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Preclosure Radiological Calculations to Support Salt Site Evaluations

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Technical Report

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ABSTRACT

The purpose of this report is to provide data, methods, and results of preclosure radiological calculations to support salt site evaluations on the basis of the U.S. Department of Energy (DOE) final siting guidelines (10 CFR Part 960). The data and methods portion is of sufficient detail to enable a reader to derive the values used and reported here. The results are presented for easy comparison with pertinent radiological regulations.

The regulations applicable to this discussion are found in 10 CFR Part 60, which defers to 10 CFR Part 20, and in 40 CFR Part 191. The regulations cover both offsite radionuclide concentrations and doses. The comparisons required by the DOE guidelines include 10 CFR Part 20 concentrations and 40 CFR Part 191 doses. To lend further insight into the radiological impacts of the presence of a high-level nuclear waste repository at a specific location, analyses of population doses and accident doses have been included.

All concentrations and doses are found to be well below applicable standards.

NOTICE TO READER

This document is a revision of the August 1984 report of the same name. The reader will notice two major differences in the results presented in the reports. First, and most important, is the incorporation of disassembly of spent fuel assemblies as the preferred handling option during the operational phase. This assumption replaces the earlier "spent fuel damage during transport scenario" as the major contributor to the normal operational source term. Second, the ingestion pathway dose was evaluated differently. Additional site-specific data were used to refine agricultural parameters used in the analysis. Also, the population ingestion dose was calculated for each crop type, based on the number of people fed by that particular crop. The earlier version used agricultural parameters only loosely based on field data, and the crop type was assumed to affect everyone in the assessment area.

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FOREWORD

The National Waste Terminal Storage (NWTS) program was established in 1976 by the U.S. Department of Energy's (DOE) predecessor, the Energy Research and Development Administration. In September 1983, this program became the Civilian Radioactive Waste Management (CRWM) Program. Its purpose is to develop technology and provide facilities for safe, environmentally acceptable, permanent disposal of high-level waste (HLW). HLW includes wastes from both commercial and defense sources, such as spent (used) fuel from nuclear power reactors, accumulations of wastes from production of nuclear weapons, and solidified wastes from fuel reprocessing.

The information in this report pertains to the radiological studies of the Salt Repository Project of the Office of Geologic Repositories in the CRWM Program.

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1.0 INTRODUCTION

The purpose of this report is to provide data, assessments, and results of the preclosure radiological calculations to support salt site evaluations. The data and assessment portion should be of sufficient detail to enable a reader to derive each number used and reported here. The results portion should be of sufficient clarity and appropriateness to enable a judgment to be easily made concerning a repository operation's compliance or noncompliance with radiological regulations.

The scope of regulations necessarily addressed includes any that pertain to the release of radioactive material to an unrestricted area during the preclosure phase of operation. This scope encompasses both U.S. Nuclear Regulatory Commission (NRC) and U.S. Environmental Protection Agency (EPA) preclosure regulations. Title 10, Code of Federal Regulations (CFR), Part 960, "General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories; Final Siting Guidelines," lists the applicable standards (introduced in Appendix A):

> Any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable requirements set forth in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR Part 191, Subpart A.

The NRC requirements as stated in 10 CFR Part 20 and 10 CFR Part 60 are discussed. This entails the calculation of the concentrations of the radionuclides released to the environment and how they compare to the standards. The requirements of the EPA, as stated in 40 CFR Part 191, which deals with the limits on radiological exposure of the general public, are discussed. Population doses and doses resulting from accidental releases are calculated. These calculations are not required by the regulations but provide additional insight into the radiological impacts of a repository in the preclosure phase. All the appropriate calculations are performed for six sites. The sites include Deaf Smith County and Swisher County in Texas; Richton Dome and Cypress Creek Dome in Mississippi; Vacherie Dome in Louisiana; and Davis Canyon and Lavender Canyon in Utah. For the purposes of this assessment, the two sites in Utah are treated as the same site and referred to as the Utah site. It should be noted that occupational radiation exposures are beyond the scope of this document.

NOTICE TO READER

This document is a revision of the August 1984 report of the same name. The reader will notice two major differences in the results presented in the reports. First, and most important, is the incorporation of disassembly of spent fuel assemblies as the preferred handling option during the operational phase. This assumption replaces the earlier "spent fuel damage during transport scenario" as the major contributor to the normal operational source term. Second, the ingestion pathway dose was evaluated differently. Additional site-specific data were used to refine agricultural parameters used in the

analysis. Also, the population ingestion dose was calculated for each crop type, based on the number of people fed by that particular crop. The earlier version used agricultural parameters only loosely based on field data, and the crop type was assumed to affect everyone in the assessment area.

2.0 U.S. NUCLEAR REGULATORY COMMISSION REQUIREMENTS

Title 10, Code of Federal Regulations (CFR), Part 60 sets no new radiological limits, but rather references 10 CFR Part 20. Part 60 states:

> The geologic repository operations area shall be designed so that until permanent closure has been completed, radiation exposures and radiation levels, and releases of radioactive materials to unrestricted areas, will at all times be maintained within the limits specified in Part 20 of this chapter....

Sections 20.105 and 20.106 of 10 CFR Part 20 contain the U.S. Nuclear Regulatory Commission's (NRC's) numerical limits for radiation exposures and releases of radioactive material in unrestricted areas. The former, entitled "Permissible Levels of Radiation in Unrestricted Areas," states:

> There may be included in any application for a license or for amendment of a license proposed limits upon levels of radiation in unrestricted areas resulting from the applicant's possession or use of radioactive material and other sources of radiation. Such applications should include information as to anticipated average radiation levels and anticipated occupancy times for each unrestricted area involved. The Commission will approve the proposed limits if the applicant demonstrates that the proposed limits are not likely to cause any individual to receive a dose to the whole body in any period of one calendar year in excess of 0.5 rem.

This standard means that the dose to the maximum exposed individual cannot exceed 0.5 rem (500 mrem). The U.S. Environmental Protection Agency (EPA) preclosure limits are more stringent than this.

The NRC standards of concern are those limiting the release of radioactive material to an unrestricted area during the preclosure phase; Section 20.106, entitled "Radioactivity in Effluents to Unrestricted Areas," states:

> A licensee shall not possess, use, or transfer licensed material so as to release to an unrestricted area radioactive material in concentrations which exceed the limits specified in Appendix B, Table II of this part, except as authorized pursuant to Section 20.302 or paragraph (b) of this section. For purposes of this section, concentrations may be averaged over a period not greater than one year.

The numerical limits included in the referenced table are for maximum permissible concentrations (MPCs).

2.1 RADIOLOGICAL SOURCE TERMS

The first input into the concentration calculations is the source term. The source term consists of the list of the specific radionuclides released and release rates that are expected during construction, operation, and

closure of the repository facility. Releases during the construction phase are expected to result from salt excavation activities only. Releases during the operational phase will result from both salt excavation and waste handling activities. Appendix B contains a memorandum which documents the origin of these source terms.

2.1.1 Releases Associated With Salt Excavation

During the excavation of salt from the repository vault, it is expected that the release of naturally occurring radionuclides contained in the salt will be enhanced. The main radionuclides of interest here are radon (^{222}Rn) and thoron (^{220}Rn) and their progeny. The excavation of the salt is expected to last the 8 years of the construction phase and continue into the 26-year-long operational phase. Since the emanation of radon and thoron is expected to occur from the mine and the pile of excavated salt, the release of natural radionuclides will last 34 years.

When radon and thoron gas emanate from the rock, their decay products become available for dispersion in the atmosphere. As the radionuclides continue to decay, the progeny begin to equilibrate with the parents. The magnitude of equilibrium disruption of the radon and thoron progeny is dependent on the extent to which the parents and progeny remain as components of the same system. Instead of calculating a value for the amount of this disruption, it was assumed that all the decay products were in a 1:1 equilibrium with the entire activity of radon and thoron in the salt, i.e., there is no equilibrium disruption. Although it is recognized that this is not a realistic picture of the release of the natural radionuclides, the release values generated represent the largest possible values and, therefore, represent a bounding situation. Appendix B includes a calculation of the equilibrium distruption that would actually be expected during salt excavation. The calculation also shows that the release values chosen for the analysis do represent bounding values.

The expected release values for the individual radionuclides were calculated as follows:

1. The expected total releases of radon and thoron from the mining of 30 million metric tons of salt, as documented in the final environmental impact statement (FEIS)[1], were used as a base for the calculation.

2. The activities of radium-226, the precursor to radon, and radium-224, the precursor to thoron, were calculated. Secular equilibrium between the radon and thoron and their precursors was assumed.

3. The activities of the radon and thoron progeny were then calculated assuming secular equilibrium with the radium-226 and radium-224. These values comprise the total amount of the radionuclides released.

Table 2-1 shows the expected releases from salt excavation. These releases will exist during both the construction and operational phases of the

Table 2-1. Salt Excavation Radionuclide Emissions

Radionuclide	Annual Release, curies (Ci)	Release Rate, Ci/s
^{222}Rn	2.9×10^{-4}	9.2×10^{-12}
^{218}Po	2.9×10^{-4}	9.2×10^{-12}
^{214}Pb	2.9×10^{-4}	9.2×10^{-12}
^{214}Bi	2.9×10^{-4}	9.2×10^{-12}
^{214}Po	2.9×10^{-4}	9.2×10^{-12}
^{210}Pb	2.9×10^{-4}	9.2×10^{-12}
^{210}Bi	2.9×10^{-4}	9.2×10^{-12}
^{210}Po	2.9×10^{-4}	9.2×10^{-12}
^{220}Rn	2.2×10^{-4}	7.0×10^{-12}
^{216}Po	2.2×10^{-4}	7.0×10^{-12}
^{212}Pb	2.2×10^{-4}	7.0×10^{-12}
^{212}Bi	2.2×10^{-4}	7.0×10^{-12}
^{212}Po	1.4×10^{-4}	4.4×10^{-12}
^{208}Ti	7.8×10^{-5}	2.5×10^{-12}

repository. The release rates listed in the table assumes that the total release occurs at a continuous rate for the 34 years.

2.1.2 Releases Associated With Waste Handling

During the routine operation of the repository, there is expected to be releases of radioactive material other than the naturally occurring nuclides. These releases originate from the disassembly of the spent fuel elements. The disassembly process consists of removing the end fittings and spacers from the assembly so that the individual rods may be placed in canisters in a geometrically efficient manner. Based on a study by the Nuclear Assurance Corporation[2], a damage rate for fuel cladding during the disassembly operation has been established. The four radionuclides listed in Table 2-2, ^{3}H, ^{14}C, ^{85}Kr, and ^{129}I, represent the volatile fission gases that will be released in the

Table 2-2. Waste Handling Radionuclide Emissions

Radionuclide	Annual Average Release, curies	Maximum Annual Release, curies
^{3}H	3.2×10^{1}	5.6×10^{1}
^{14}C	2.6×10^{-1}	4.4×10^{-1}
^{85}Kr	1.9×10^{4}	3.4×10^{4}
^{129}I	3.2×10^{-2}	5.6×10^{-2}

event of cladding damage. The actual release values were calculated as follows (see Appendix B):

1. The spent fuel is 6.5 years out-of-reactor.

2. A damage fraction of 0.005 was established. This is based on the conservative assumption that 1.0 percent of the rods stick within the assembly. It is also assumed that 50 percent of the stuck rods are damaged as they are forced out of the assembly.

3. The number of damaged rods that can be expected in 1 year is calculated by multiplying the number of rods received per year by the damage fraction. The maximum annual release, used in the MPC calculations, is calculated based on the maximum number of rods expected in 1 year. The average annual release, used in the dose assessment calculations, is based on an average annual rod receipt rate.

4. The amounts released are determined by multiplying the number of damaged rods, either maximum or average, by the emission from the damage of one rod.

The values listed in Table 2-2 are based on the receipt of only spent fuel as a waste form. While other designs call for the receipt of vitrified waste, the assumption of 100 percent spent fuel as the waste form bounds the release. This is the case since there are no routine operational releases associated with precanistered, vitrified wastes because of the absence of the volatile radionuclides.

2.1.3 Other Releases

Another release that might be expected during the preclosure phase is attributed to the damage of rods during the transportation of the fuel to the repository site. It is expected that as many as six rods per year could be damaged via this scenario. Since the operational source term considers the

damage of 6,400 rods per year, this term is considered insignificant and was not included in the analysis.

Releases of radioactive material may also be attributed to the decommissioning and closure of the repository facility. This release is not considered here because of the absence of a repository decommissioning data base, but documentation of all previous decommissioning studies indicates that the radioactive emissions during decommissioning will be far less than during operation.[3] For instance, it has been estimated[4] that during the complete dismantling of a 1,175-megawatt electric (MWe) pressurized-water reactor, only 85 microcuries (μCi) of radioactive material would be released to the environment. Even though there is a difference between a reactor and a repository, the reactor analogy appears to be appropriate to provide an estimate of the upper bound for potential repository impacts. This is the case since release values are expected to be much smaller in the case of the repository, partially because there will be less residual mobile contamination at a repository than at a power reactor.

2.2 METEOROLOGY

All of the expected releases from repository facilities during the preclosure phase will be airborne releases. For the purposes of the concentration and dose calculations, the atmospheric transport and dispersion of the radionuclides must be modeled. For this modeling to be done for the sites, site-specific meteorology must be known. Data such as wind speed, Pasquill stability class frequency, and material release heights are used to calculate the dispersion characteristics.

The atmospheric dispersion submodel within the computer code DACRIN[5] is used to model the atmospheric transport of the radioactive material. This code uses the following equation:

$$\chi = \frac{Q}{\pi u \sigma_y \sigma_z} \exp(-h^2/2\sigma_z^2) \qquad (2\text{-}1)$$

where

χ = ground-level concentration, Ci/m^3
Q = radionuclide release rate, Ci/s
u = annual average wind speed, m/s
σ_y = horizontal dispersion coefficient, m
σ_z = vertical dispersion coefficient, m
π = 3.1415....
h = height from which the radionuclide is released, m

Table 2-3 shows the stability class frequency for the areas of concern.[6,7,8] Note that in the areas where there are more than one site (Texas and Mississippi), the sites are assumed to have similar meteorology. This similarity in meteorology is the case since the sites are relatively close to one another and the meteorological data used are for a major city near the sites. The stability class with the highest frequency for each of the sites is one of the inputs in DACRIN. For the case of the Utah site, a stability

Table 2-3. Atmospheric Stability Class Distributions

Stability Class	Frequency, %			
	Texas	Utah[a]	Mississippi	Louisiana
A	0.3	0.0	1.1	1.0
B	2.0	0.0	7.9	7.0
C	9.1	0.0	12.2	12.8
D	68.8	0.0	20.2	21.4
E	14.7	0.0	20.0	20.8
F	5.1	100.0	38.6	37.0

(a) A stability class of F is assumed for the Utah site.

Table 2-4. Calculated χ/Q Values for Normal Conditions

Distance, m(a)	χ/Q, s/m^3			
	Texas	Utah	Mississippi	Louisiana
	Ground Level (0-Meter) Release			
240(b)	2.75×10^{-4}	8.85×10^{-3}	2.68×10^{-3}	2.33×10^{-3}
8,045	8.93×10^{-7}	3.15×10^{-5}	9.55×10^{-6}	8.29×10^{-6}
24,135	2.01×10^{-7}	8.51×10^{-6}	2.58×10^{-6}	2.24×10^{-6}
40,225	9.62×10^{-8}	4.63×10^{-6}	1.40×10^{-6}	1.22×10^{-6}
56,315	6.16×10^{-8}	3.18×10^{-6}	9.63×10^{-7}	8.36×10^{-7}
72,405	4.49×10^{-8}	2.41×10^{-6}	7.32×10^{-7}	6.35×10^{-7}
Maximum	2.75×10^{-4}	8.85×10^{-3}	2.68×10^{-3}	2.33×10^{-3}
Average	1.34×10^{-5}	3.91×10^{-4}	1.08×10^{-4}	1.06×10^{-4}
	61-Meter Release			
240(b)	3.67×10^{-12}	0.0	0.0	0.0
8,045	7.91×10^{-7}	1.16×10^{-5}	3.51×10^{-6}	3.05×10^{-6}
24,135	1.93×10^{-7}	5.34×10^{-6}	1.62×10^{-6}	1.41×10^{-6}
40,225	9.40×10^{-8}	3.31×10^{-6}	1.00×10^{-6}	8.70×10^{-7}
56,315	6.06×10^{-8}	2.40×10^{-6}	7.26×10^{-7}	6.31×10^{-7}
72,405	4.43×10^{-8}	1.88×10^{-6}	5.71×10^{-7}	4.96×10^{-7}
Maximum	4.32×10^{-6}	1.30×10^{-5}	3.94×10^{-6}	3.43×10^{-6}
Average	4.87×10^{-7}	4.86×10^{-6}	1.56×10^{-6}	1.38×10^{-6}
Stability Class	D	F	F	F
Mean Wind Speed, m/s	6.1	1.0	3.3	3.8

(a) Represent midpoints of five 10-mile-wide annuli.
(b) Site boundary.

class of F and an average annual wind speed of 1 m/s is assumed. These assumptions represent a worst case for the meteorology and is used since the meteorology within the canyons is difficult to determine without site-specific data. Table 2-4 shows the other inputs[6,7,8] into DACRIN and the dispersion (χ/Q) values that were calculated by the code for the four areas of interest. The two release heights shown represent the release heights of the two source terms. The natural radionuclides are released from ground level, i.e., from the mine ventilation and the salt pile; and the operational nuclides are released from 61 meters, i.e., from the exhaust stack of the fuel handling facility.

2.3 MAXIMUM PERMISSIBLE CONCENTRATION ANALYSIS

The phenomenon being characterized in this analysis is the atmospheric dilution of the radionuclides being released. Applying the dispersion values to the radionuclide emission rates will enable the calculation of the dilution and, therefore, the concentrations of the released material at particular points in the region. Since there are two release points, local maximum χ/Q values occur at two different locations. Therefore, the concentrations were calculated for points between the two maximum points to see where a combined maximum χ/Q existed. For the purposes of this calculation, dispersion values for the Utah site were used since it can be seen in Table 2-4 that these values will yield the greatest concentrations. The steps of the calculation are:

1. An emission rate is established for each radionuclide by dividing the annual release rate for each nuclide by the number of seconds in 1 year. This is done because the regulations allow for the averaging over the period of 1 year. The maximum annual release values for the operational source term are used. The resulting emission values are in microcuries per second after converting from curies.

2. The emission rate is then multiplied by the χ/Q for the distance for which the calculation is being made. This yields concentrations in microcuries per cubic centimeter at that distance. The distances used were 240, 1,000, 2,000, 3,000, 4,000, and 5,000 meters. (The 240- and 5,000-meter distances represent the maximum χ/Q points for the ground level and 61-meter releases, respectively.)

3. The concentrations for each radionuclide are then divided by their respective MPC values. These concentration-to-MPC ratios are then summed for every radionuclide. The NRC standard states that the sum of these ratios must be less than or equal to unity.

Table 2-5 shows the results of this calculation at 5,000 meters. This point is where the maximum sum of the concentration-to-MPC ratios occurs. The sum at this point is 0.05. This means that the repository facility combined releases during the operational phase are only 5 percent of the limit. This analysis was done only for the operational phase since the releases during that time are always greater than during the construction phase. Table 2-5 also shows that ^{85}Kr is the only radionuclide that approaches the MPC limit.

Table 2-5. 10 CFR Part 20 Maximum Permissible Concentration Comparison

Radionuclide	Emission Rate, μCi/s	Concentration,(a) μCi/cm^3	MPC, μCi/cm^3	Sum of Conc-to-MPC Ratios
		Waste Handling		
^{3}H	1.7	2.2×10^{-11}	2×10^{-7}	1×10^{-4}
^{14}C	1.4×10^{-2}	1.9×10^{-13}	1×10^{-6}	2×10^{-7}
^{85}Kr	1.0×10^{3}	1.3×10^{-8}	3×10^{-7}	5×10^{-2}
^{129}I	1.7×10^{-3}	2.2×10^{-14}	2×10^{-14}	1×10^{-3}
		Salt Excavation		
^{222}Rn	9.2×10^{-6}	1.8×10^{-15}	3×10^{-9}	6×10^{-7}
^{214}Pb	9.2×10^{-6}	1.8×10^{-15}	3×10^{-6}	6×10^{-10}
^{214}Bi	9.2×10^{-6}	1.8×10^{-15}	3×10^{-6}	6×10^{-10}
^{210}Pb	9.2×10^{-6}	1.8×10^{-15}	4×10^{-12}	5×10^{-4}
^{210}Bi	9.2×10^{-6}	1.8×10^{-15}	2×10^{-10}	9×10^{-6}
^{210}Po	9.2×10^{-6}	1.8×10^{-15}	2×10^{-11}	9×10^{-5}
^{220}Rn	7.0×10^{-6}	1.4×10^{-15}	1×10^{-8}	1×10^{-7}
^{212}Pb	7.0×10^{-6}	1.4×10^{-15}	6×10^{-10}	2×10^{-6}
^{212}Bi	7.0×10^{-6}	1.4×10^{-15}	3×10^{-9}	5×10^{-7}
^{208}Tl	2.5×10^{-6}	5.5×10^{-15}	3×10^{-6}	2×10^{-9}
			Operational Total =	5×10^{2}

(a) The χ/Q values used to calculate the concentrations were:

For ^{3}H, ^{14}C, ^{85}Kr, and ^{129}I: 1.3×10^{-11} s/cm^3.
For all other radionuclides: 2.0×10^{-10} s/cm^3.

Most of the radionuclides are well below their limits. Note that the radionuclides ^{218}Po, ^{214}Po, ^{216}Po, and ^{212}Po were excluded from the calculation because of their short half-lives. It is assumed that they decay before they reach the unrestricted area.

3.0 U.S. ENVIRONMENTAL PROTECTION AGENCY REQUIREMENTS

The U.S. Environmental Protection Agency (EPA) preclosure requirements are documented in 40 CFR Part 191. These standards were developed for application to a high-level nuclear waste repository. Regulation 40 CFR 191.03 states:

> Management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities regulated by the Commission or by Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from: (1) discharges of radioactive material and direct radiation from such management and storage and (2) all operations covered by Part 190; shall not exceed 25 millirems to the whole body....

It can be seen here that the limit established by the EPA, 25 mrem/yr to the whole body, is much more stringent than the U.S. Nuclear Regulatory Commission (NRC) limit of 500 mrem/yr to the whole body. Therefore, the objective of this section is to illustrate the calculations used and how the results of those calculations compare with the 25-mrem limit. It must be shown that the dose equivalent resulting from the repository releases are only a small fraction of the limit, so, when combined with doses from other facilities regulated under 40 CFR Part 190, the limit is not surpassed. Note that this limit is an annual limit which applies to the maximum exposed individual.

The calculations involved in the dose assessment concern the evaluation of exposures through three pathways. These are the ingestion of food that has been contaminated with radionuclides, submersion in the plume that contains the radioactive material, and the inhalation of contaminated air. It is important to establish that the exposure via all three of these pathways is due to the airborne release of the radionuclides during the preclosure phase. Therefore, the source terms and meteorological parameters presented in the earlier maximum permissible concentration (MPC) analysis apply to this analysis as well.

3.1 MAXIMUM EXPOSED INDIVIDUAL DOSE ASSESSMENT

3.1.1 Food Ingestion Pathway

One pathway for the exposure of the general public to radiation is through the ingestion of food that has been contaminated by radioactive material. The contamination can occur from the direct deposition of radioactive material, the uptake of the radioactive material through the root system of the plant, or the uptake of the material by animals that graze on plants contaminated with the radionuclides. In the case of uptake by animals, once ingested into their system, the material is transferred to the flesh or the milk of the animal which is then consumed by people. To evaluate this exposure pathway, the types of crops and animals raised in the area of the site must be known. Agricultural parameters such as growing periods, storage

times, acreage, and crop yields must also be known so that the radionuclides can be properly accounted for in the food chain.

The computer code PABLM[9] has been used to model the ingestion pathway. PABLM includes a large number of biosphere pathway submodels that are used to evaluate the transport of radionuclides through terrestrial pathways. The code is capable of handling 19 ingestion pathways, including vegetable crops, grains, animal products, seafood, and water. Also, four external exposure pathways can be assessed, including exposure from field deposition and water recreation.

For all exposure pathways, radionuclides can be specified to be deposited over an extended period of time and are assumed to be removed from the soil only by radioactive decay. Leaching from the soil and other removal mechanisms which could act to decrease exposure are not taken into account.

PABLM can take into consideration both waterborne radionuclide releases and airborne releases; the latter is the expected case for the preclosure operations of the repository. The code uses dispersion parameters, χ/Q values, to calculate the deposition rate of the radionuclides onto the plants and soil. Plant accumulation factors, built into libraries in the code, are used to relate the concentrations deposited to the concentrations in the plants. The concentration of nuclides in animal products, such as milk and meat, depends on the animals' consumption of contaminated forage and the radionuclide concentrations in that forage. The ultimate exposure to humans is dependent on the rate at which the contaminated food is ingested and the radionuclide concentration in the foodstuff at the time of ingestion, which is dependent on the radioactive decay during storage of the food.

In calculating the internal dose to an individual, the code can model the exposure to any of 23 organs and from 100 radionuclides in a mixture. The organ doses are based on the model documented in International Commission on Radiological Protection (ICRP) Publication 2[10] for internally deposited radionuclides. The 1-year dose or a dose commitment from an extended release can be calculated. Also, the dose to the maximum exposed individual or the exposure to a population can be computed.

The external exposure pathways also use the concentration of the deposited nuclides. Using external dose conversion factors, and time in contact with the external radiation fields, i.e., time spent swimming in contaminated water or time working in contaminated fields, the code calculates an external exposure. In the case of the radionuclides that are of concern during preclosure, those pathways do not contribute to the overall dose.

The code outputs the dose by organ and radionuclide and by organ and food type in a tabular form.

Some of the agricultural inputs[11,12,13,14,15,16,17,18,19] into PABLM for the salt repository sites are shown in Tables 3-1 through 3-5. Note here that the Richton and Cypress Creek sites in Mississippi are treated as one site because the close proximity of the sites to one another made it impossible to distinguish any differences in most of the input parameters for the two sites. Where there were differences, the input that would yield the higher dose was used. These inputs were developed as follows:

Table 3-1. Deaf Smith Ingestion Pathways Input Data

Food Type	Acres Grown, thousand	Growing Period, days	Yield kg/m^2	Consumption Rate, kg/yr/person	Affected Population
Leafy veg.	0.47	90	2.6	14.5	217,000
Other above-ground veg.	0.34	60	1.0	11.4	125,100
Potatoes	2.91	90	2.4	24.6	217,000
Other root veg.	2.30	90	2.5	9.9	217,000
Melons	0.98	90	1.3	7.8	217,000
Wheat	270.9	90	0.1	54.0	217,000
Other grain	22.1	90	0.3	4.0	217,000
	Animal Product, million kg				
Milk	22.0	90	1.1	111.4	197,500
Beef	193.2	90	1.1	35.2	217,000
Pork	5.40	90	1.1	28.9	187,000
Poultry	0.31(a)	90	1.1	28.6	10,900

(a) Calculated value, based on 5 percent criterion.

Table 3-2. Swisher Ingestion Pathways Input Data

Food Type	Acres Grown, thousand	Growing Period, days	Yield kg/m^2	Consumption Rate, kg/yr/person	Affected Population
Leafy veg.	0.47	90	2.6	14.5	248,000
Other above-ground veg.	4.03	60	1.1	6.3	248,000
Potatoes	7.63	90	2.4	24.6	248,000
Other root veg.	4.08	90	2.5	9.9	248,000
Melons	1.24	90	1.2	7.8	248,000
Wheat	214.0	90	0.1	54.0	248,000
Other grain	11.9	90	0.3	4.0	248,000
	Animal Product, million kg				
Milk	21.4	90	1.1	111.4	191,800
Beef	177.0	90	1.1	35.2	248,000
Pork	4.35	90	1.1	28.9	150,400
Poultry	0.35(a)	90	1.1	28.6	12,400

(a) Calculated value, based on 5 percent criterion.

Table 3-3. Utah Ingestion Pathways Input Data

Food Type	Acres Grown, thousand	Growing Period, days	Yield kg/m^2	Consumption Rate, kg/yr/person	Affected Population
Potatoes	0.12	90	1.7	24.6	16,500
Wheat	38.4	90	0.1	54.0	10,765
Other grain	5.77	90	0.3	4.0	16,500
	Animal Product, million kg				
Milk	11.8	90	0.9	111.4	16,500
Beef	14.4	90	0.9	35.2	16,500
Pork	0.36	90	0.9	28.9	12,600
Poultry	0.003	90	0.9	28.6	100

Table 3-4. Mississippi Ingestion Pathways Input Data

Food Type	Acres Grown, thousand	Growing Period, days	Yield kg/m^2	Consumption Rate, kg/yr/person	Affected Population
Leafy veg.	0.05(a)	90	1.5(b)	15.0(b)	18,900
Other above-ground veg.	0.10(a)	60	0.7(b)	15.0(b)	18,900
Potatoes	0.03(a)	90	4.0(b)	24.6	18,900
Other root veg.	0.56	90	1.1	1.6	377,000
Melons	2.0	90	1.0	5.0	377,000
Wheat	70.4	90	0.2	54.0	377,000
	Animal Product, million kg				
Milk	58.1	90	0.4	111.4	377,000
Beef	38.1	90	0.4	35.2	377,000
Pork	78.5	90	0.4	28.9	271,700

(a) Calculated value, based on 5 percent criterion.
(b) Default value.

Table 3-5. Vacherie Ingestion Pathways Input Data

Food Type	Acres Grown, thousand	Growing Period, days	Yield kg/m^2	Consumption Rate, kg/yr/person	Affected Population
Leafy veg.	0.06(a)	90	1.5(b)	15.0(b)	25,300
Other above-ground veg.	0.14	60	0.9	6.6	77,500
Potatoes	0.22	90	0.9	24.6	32,500
Other root veg.	1.25	90	1.1	1.6	506,000
Berries	0.07	90	0.7	1.2	147,700
Wheat	82.9	90	0.2	54.0	506,000
	Animal Product, million kg				
Milk	76.1	90	0.4	111.4	506,000
Beef	15.5	90	0.4	35.2	440,300
Pork	1.02	90	0.4	28.9	35,300
Poultry	1.31	90	0.4	28.6	45,900

(a) Calculated value, based on 5 percent criterion.
(b) Default value.

- Food type - The types listed here represent the food pathways available in PABLM that are viable exposure pathways within the area surrounding the site. For the purposes of the assessment, this area was assumed to include the counties within a 50-mi (80.5-km) radius of the site. Seafood pathways were not considered since the expected release will be airborne and there are no significant bodies of water within the 50-mi (80.5-km) radius area.

- Acres grown - This parameter represents the amount of area devoted to growing that food type within the surrounding area. It is used in calculating the "affected population." In the cases where the food type is known to be present in an area but in acreage too small to be recorded in state agricultural statistics, a "5 percent criterion" was used to calculate an approximate area. This value represents the acreage that would support 5 percent of the population living in the surrounding area, i.e., the area required to grow enough of the crop to supply the annual consumption needs of that population.

- Animal product - This value represents the weight of animal product produced in the area. As with "acres grown," this value is used to establish an "affected population value." In some cases, the 5 percent criterion was applied.

- Growing period - This value represents the time involved from the time the food is planted to the time it is harvested. This value is used in the code to model the buildup of radionuclides in the food chain. However, the radionuclides that are of concern in this analysis all build up quickly and, therefore, this parameter is not very significant.

- Yield - This value represents the yield of the crop and is an average value for the surrounding area for the food type, as documented in State statistical reports. The value was determined by calculating a yield that was weighted by food type component. For example, the yield for leafy vegetable would be calculated by multiplying the yields of lettuce, cabbage, spinach, etc., by the acres of each component and then dividing by the total acreage of the food type. Therefore, if one food type component was more prevalent, it would be reflected in the yield. In the case of the animal products, this value represents the yield of the forage, either corn or hay. In some cases, this value was not available, so a default value that was developed for earlier assessments is used.

- Consumption rate - The consumption parameters are national average figures.[11] The values listed in the tables are the sum of the consumption rates of components of a particular food type. For example, the melon consumption rate is the sum of the consumption rates of watermelon, honeydew melons, canteloupes, etc. Again, in some cases, default values are used.

- Affected population - This value is determined by multiplying the area grown, in square meters, by the yield, in kilograms per square meter, and then dividing by the individual consumption, in kilograms per year per person. This value then represents the number of people fed by the food grown. In the case of the animal products, the quantities listed in the first column of Tables 3-1 through 3-5 were divided by the appropriate consumptions. When the value exceeded the number of people living within the 50-mi (80.5-km) radius of the site, the value was substituted with the actual population.

Another parameter which is used by PABLM is the dispersion characteristics of the site. The code requires that a χ/Q value be supplied as input. For this analysis, an average χ/Q value for the surrounding area was chosen. This value was calculated by integrating the function of χ/Q and distance over the 50-mi (80.5-km) distance. This calculation assumes that the foodstuffs are grown uniformly throughout the 50-mi (80.5-km) radius area. These average values are shown in Table 2-3. Also inputted into the code is the storage time of the foodstuff after harvest. This parameter allows for radioactive decay and thus reduces the concentrations in the food. For this analysis, the storage time is assumed to be zero, i.e., no credit was taken for radioactive decay.

3.1.2 Submersion and Inhalation Pathways

The remaining two exposure pathways are submersion in the radioactive effluent plume and inhalation of contaminated air. Analysis of both of these pathways depends on the concentration of the radionuclides in the air. Again, the atmospheric dispersion characteristics of the sites are necessary to evaluate the exposure. These χ/Q values are then applied to specific dose factors and release quantities to determine the dose. Both annual doses and dose commitments from releases over an extended period of time may be calculated.

The inhalation dose was calculated as follows:

1. The maximum χ/Q values were established for the sites. The maximum value yields the greatest dose. This assumes that the maximum exposed individual is at the point of maximum deposition at all times.

2. The χ/Q, in seconds per cubic meter, is multiplied by the annual release rate, in curies per year. This establishes a concentration value.

3. The concentration value is then multiplied by an inhalation rate of 20 m^3 of air per day.[20] This results in the quantity of radionuclide intake for 1 year.

4. The intake value is multiplied by an inhalation dose conversion factor.[21] The dose factor, with units of millirem per microcurie, calculates a 50-year dose commitment from an annual release. When reporting the results, this value is documented as the annual dose, even though using the 50-year dose commitment over estimates the

annual dose. Multiplying by the length of time for the release establishes the 50-year dose commitment for the entire release. The dose factors are shown in Table 3-6.

5. Unit conversion factors are applied to get the inhalation dose in units of millirem per year for the annual dose and millirem for the dose commitment.

The submersion dose is calculated in the same manner as discussed for the inhalation pathway. In the submersion dose calculation however, the inhalation rate is excluded from the calculation. Also, specific submersion dose factors[22] are used. These factors, with units of millirem per year per microcurie per cubic centimeter, can be seen in Table 3-7.

A simple code was developed to aid in the calculation of inhalation and submersion dose. ISDOSE (Inhalation and Submersion DOSE) will calculate annual dose equivalents and 50-year dose commitments for both maximum exposed individual and population dose cases. The code contains the dose conversion factors in libraries for all of the radionuclides that are of concern to the analysis. The program simultaneously calculates the exposure from both of the pathways using the method discussed previously and outputs the results in a tabular form by pathway and radionuclide.

3.2 RESULTS

To evaluate the exposure results, the dose equivalents from the three pathways must be added. Since the PABLM output contains the dose to specific organs, while the submersion and inhalation doses are for the whole body, a method outlined by the ICRP[23] is used to manipulate the PABLM output to establish a whole body dose. The technique is taken from the following:

> For stochastic effects the Commission's recommended dose limitation is based on the principle that the risk should be equal whether the body is irradiated uniformly or whether there is nonuniform irridation.
>
> This condition will be met if:
>
> $$\sum W_T H_T \leq H_{wb,L}$$
>
> where W_T is a weighting factor representing the portion of the stochastic risk resulting from tissue (T) to the total risk, when the whole body is irradiated uniformly, H_T is the annual dose equivalent in tissue (T), $H_{wb,L}$ is the recommended annual dose equivalent limit for uniform irradiation of the whole body.
>
> The values of W_T recommended by the Commission are shown below:

Tissue	W_T
Gonads	0.25
Breasts	0.15
Red bone marrow	0.12
Lung	0.12

Table 3-6. Inhalation Dose Conversion Factors(21)

Radionuclide	Dose Factor,(a) mrem/μCi	Radionuclide	Dose Factor,(a) mrem/μCi
^{3}H (HTO)	6.3×10^{-2}	^{220}Rn	NA
^{14}C	2.4×10^{-2}	^{222}Rn	NA
^{54}Mn	6.3	^{238}Pu	4.5×10^{5}
^{60}Co	1.5×10^{2}	^{239}Pu	5.2×10^{5}
^{63}Ni	3.1	^{240}Pu	5.2×10^{5}
^{85}Kr	NA	^{241}Pu	1.0×10^{4}
^{90}Sr	1.3×10^{3}	^{241}Am	5.2×10^{5}
^{90}Y	8.1	^{242}Cm	1.7×10^{4}
^{95}Nb	4.4	^{244}Cm	2.7×10^{5}
^{106}Ru	4.4×10^{2}	^{210}Po	7.88×10^{3}
^{125}Te	6.7	^{212}Bi	1.74×10^{1}
^{129}I	1.7×10^{2}	^{214}Bi	5.92
^{134}Cs	4.8×10^{1}	^{208}Tu	9.1×10^{3}
^{137}Cs	3.2×10^{1}	^{218}Po	1.91×10^{1}
^{144}Ce	3.5×10^{2}	^{214}Po	0.0
^{154}Eu	2.6×10^{2}	^{216}Po	0.0
^{210}Bi	1.9×10^{2}	^{212}Po	0.0
^{210}Pb	1.3×10^{4}	^{212}Pb	1.6×10^{2}
^{214}Pb	6.7		

NA = not applicable.
(a) Converted from Sievert per Becquerel.

Table 3-7. Submersion Dose Conversion Factors[22]

Radionuclide	Dose Factor,[a] mrem/yr per µCi/cm^3	Radionuclide	Dose Factor,[a] mrem/yr per µCi/cm^3
^{3}H (HTO)	0.0	^{220}Rn	2.67×10^{6}
^{14}C	2.18×10^{5}	^{222}Rn	1.98×10^{5}
^{54}Mn	4.44×10^{9}	^{238}Pu	4.7×10^{5}
^{60}Co	1.31×10^{10}	^{239}Pu	4.26×10^{5}
^{63}Ni	0.0	^{240}Pu	4.63×10^{5}
^{85}Kr	2.66×10^{7}	^{241}Pu	0.0
^{90}Sr	1.07×10^{7}	^{241}Am	9.66×10^{7}
^{90}Y	7.33×10^{7}	^{242}Cm	5.25×10^{5}
^{95}Nb	4.03×10^{9}	^{244}Cm	4.48×10^{5}
^{106}Ru	0.0	^{210}Po	0.0
^{125}Te	5.03×10^{7}	^{212}Bi	8.25×10^{9}
^{129}I	4.29×10^{7}	^{214}Bi	4.4×10^{5}
^{134}Cs	8.14×10^{9}	^{208}Tu	4.48×10^{4}
^{137}Cs	8.36×10^{6}	^{218}Po	7.66×10^{4}
^{144}Ce	9.44×10^{7}	^{214}Po	$1.01 \text{ z } 10^{9}$
^{154}Eu	6.59×10^{9}	^{216}Po	0.0
^{210}Bi	2.64×10^{7}	^{212}Po	2.01×10^{10}
^{210}Pb	6.85×10^{6}	^{212}Pb	7.55×10^{8}
^{214}Pb	1.28×10^{9}		

(a) Converted from Sievert per year per Becquerel per cubic centimeter.

Tissue	W_T
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30

For this application, the organs that contributed to the dose are total body, bone, and thyroid. We found the total ingestion dose by summing the products of the weighting factors listed for those organs and the individual organ doses. The W_T for total body is 1.0. The resulting dose is a whole body dose from the ingestion of contaminated food. Also, since the inputs for food consumption were average values, the final results were multiplied by 1.5[24] to take into consideration the fact that the maximum exposed individual's food intake is above the average value. This value is added to the dose equivalent values for the submersion and inhalation pathways. Note that in the case of the submersion and inhalation doses for operational releases, the locations of the maximum concentration for the two source terms differ. For this calculation, it is assumed that they occur at the same location and the doses from each of the source terms are added. This assumption helps to bound the dose values.

Table 3-8 gives the resulting maximum individual dose for each pathway and the totals for each salt repository site for the two phases. All the doses are below the EPA limit of 25 mrem. The maximum dose occurring at the Utah site during operation is 1.8 mrem. Table 3-9 shows the 50-year dose commitment from the total releases during the construction and operational phases. No limits exist for comparison with these results. Table 3-10 shows which radionuclides contribute the most dose for each pathway. The percentages given represent the percent of the total dose contributed by each pathway. It can be seen from this table that the annual doses are dominated by inhalation of the natural radionuclides. However, for the 50-year dose commitments, the ingestion pathway becomes increasingly significant, although still less significant than the inhalation pathway.

Table 3-8. Maximum Individual Annual Dose

Site	Exposure Pathway Dose, mrem			Total[a]
	Inhalation	Submersion	Ingestion	
		Construction		
Deaf Smith	3.39×10^{-2}	4.77×10^{-5}	9.8×10^{-3}	4.4×10^{-2}
Swisher	3.39×10^{-2}	4.77×10^{-5}	8.6×10^{-3}	4.3×10^{-2}
Utah	1.09	1.53×10^{-5}	1.8×10^{-1}	1.3
Vacherie	2.87×10^{-1}	4.04×10^{-4}	5.7×10^{-2}	2.4×10^{-1}
Richton	3.30×10^{-1}	4.65×10^{-4}	7.7×10^{-2}	4.1×10^{-1}
Cypress Creek	3.30×10^{-1}	4.65×10^{-4}	7.7×10^{-2}	4.1×10^{-1}
		Operation		
Deaf Smith	4.45×10^{-2}	6.93×10^{-2}	5.5×10^{-2}	1.7×10^{-1}
Swisher	4.45×10^{-2}	6.93×10^{-2}	5.1×10^{-2}	1.6×10^{-1}
Utah	1.09	2.10×10^{-1}	5.2×10^{-1}	1.8
Vacherie	2.87×10^{-1}	5.54×10^{-2}	2.0×10^{-1}	5.4×10^{-1}
Richton	3.31×10^{-1}	6.36×10^{-2}	2.7×10^{-1}	6.6×10^{-1}
Cypress Creek	3.31×10^{-1}	6.36×10^{-2}	2.7×10^{-1}	6.6×10^{-1}

(a) This is the annual dose from a 1-year exposure to the released radionuclides.

Table 3-9. Maximum Individual 50-Year Dose Commitment

Site	Exposure Pathway Dose, mrem			Total[a]
	Inhalation	Submersion	Ingestion	
		Construction		
Deaf Smith	2.71×10^{-1}	3.81×10^{-4}	1.5×10^{-1}	4.2×10^{-1}
Swisher	2.71×10^{-1}	3.81×10^{-4}	1.4×10^{-1}	4.1×10^{-1}
Utah	8.72	1.23×10^{-2}	2.8	1.2×10^{1}
Vacherie	2.30	3.23×10^{-3}	8.9×10^{-1}	3.2
Richton	2.64	3.72×10^{-3}	1.1	3.7
Cypress Creek	2.64	3.72×10^{-3}	1.1	3.7
		Operation		
Deaf Smith	8.97×10^{-1}	1.80	2.9	5.6
Swisher	8.97×10^{-1}	1.80	2.8	5.5
Utah	2.84×10^{1}	5.45	2.7×10^{1}	6.1×10^{1}
Vacherie	7.47	1.43	9.9	1.9×10^{1}
Richton	8.59	1.65	1.2×10^{1}	2.2×10^{1}
Cypress Creek	8.59	1.65	1.2×10^{1}	2.2×10^{1}

(a) This is a 50-year dose commitment from exposure to an 8-year release of radionuclides during construction and a 26-year release of radionuclides during operation of the repository.

Table 3-10. Critical Nuclides in Dose Assessment

Inhalation	Submersion	Ingestion
Annual Dose - Construction		
^{210}Pb	^{212}Bi	^{210}Pb
^{210}Po	^{212}Po	^{210}Po
(86%)	(~0%)	(14%)
Annual Dose - Operation		
^{210}Pb	^{85}Kr	^{129}I
^{210}Po		^{210}Pb
(60%)	(12%)	(29%)
50-Year Dose Commitment - Construction		
^{210}Pb	^{212}Bi	^{210}Pb
^{210}Po	^{212}Po	^{210}Po
(76%)	(~0%)	(24%)
50-Year Dose Commitment - Operation		
^{210}Pb	^{85}Kr	^{129}I
^{210}Po		^{210}Pb
(47%)	(9%)	(44%)

4.0 POPULATION DOSE ASSESSMENT

The U.S. Environmental Protection Agency (EPA) dose equivalent standards were compared with the projected doses to be delivered by the operation of preclosure repository facilities. These standards address only the exposure of an individual, the maximum exposed individual. Another dose assessment must be made to calculate the dose to the population surrounding the site. To make this calculation, additional dispersion parameters and a demographic makeup for the area must be developed. After this development, the assessment is very similar to the analysis made to calculate the maximum individual dose. An assessment of this type presents a more complete analysis of the radiological impacts on the area from preclosure operations, although it is not required in the regulations.

The source terms used for this analysis are the same as documented previously. In the case of the meteorological data, dispersion values were calculated for 5, 15, 25, 35, and 45 miles from the site. These distances represent the midpoints of five 10-mile-wide annuli. This calculation allows for an analysis of the population dose for persons living within a 50-mile radius of the site. Also, the frequency with which the wind blows toward a certain direction was determined. Table 2-4 showed the χ/Q values for the distances of concern.

4.1 DEMOGRAPHY OF SITES

The demography around each site was developed to conform with the meteorological data format. A system of circular grids was designed to map out the population in the area around each site. The grids are comprised of five annuli of 10-, 20-, 30-, 40-, and 50-mile radii. Each annulus was then divided into 16 sections, representing the 16 wind directions for which wind direction frequencies were obtained. Each of the grids was developed as follows:

1. A map of the region was developed by plotting data contained within the cartographic data base available in the SAS computer program.[25] Then, the circular grids were overlayed on the map with the centers of the annuli positioned at the site location. These circular grids then defined the area to be used in the population dose assessment.

2. The population data[8,26,27,28,29] for the assessment areas were obtained. These data included the population of each of the counties affected by the assessment, the county area, and the population of the population centers with more than 500 people.

3. The population within each segment of the population grid was determined. A segment is defined as 1/16 of an annulus. This population figure was calculated in the following manner:

   a. The population of the population centers were substracted for the county total populations. This established a "rural" population value for each county.

b. The rural population was divided by the county area. This established a "rural density." These rural densities were then used to develop the site grids.

c. The appropriate rural density to be used to calculate the population of a segment was determined. The density was used for the county that comprised the greatest area within the segment. The proper density value was then multiplied by the area represented by the segment of concern. This calculation resulted in a "rural population" for the segment. This figure was recorded on the population grids in that segment.

d. The population centers within the affected area were then recorded separately onto the grid as they would appear on a map.

4. Finally, the total population within the affected area was determined by adding the values within each segment together.

Figures 4-1 through 4-6 show the population diagrams for each of the sites. From these diagrams, a value for the total population residing within the 50-mile radius area can be established. These values for the six areas are:

Site	Value
Deaf Smith	217,000
Swisher	248,000
Utah	16,500
Vacherie	506,000
Richton	337,000
Cypress Creek	377,000

4.2 ASSESSMENT

As in the case of assessing the dose to the maximum exposed individual, three exposure pathways must be evaluated for population dose. Again, PABLM is used for the analysis of the contribution of the food ingestion pathway and ISDOSE is used to assess the inhalation and submersion pathways. However, each code is used differently from the single person case. The population dose is defined as the dose equivalent, in man-millirem, to the population residing within a 50-mi (80.5-km) radius of the site. Exposures to persons outside this area are not addressed.

To assess the dose from ingestion of contaminated food, PABLM is run in the same manner and with the same inputs as described previously. However, the difference arises in the manner in which the output of PABLM is manipulated. The method used is as follows:

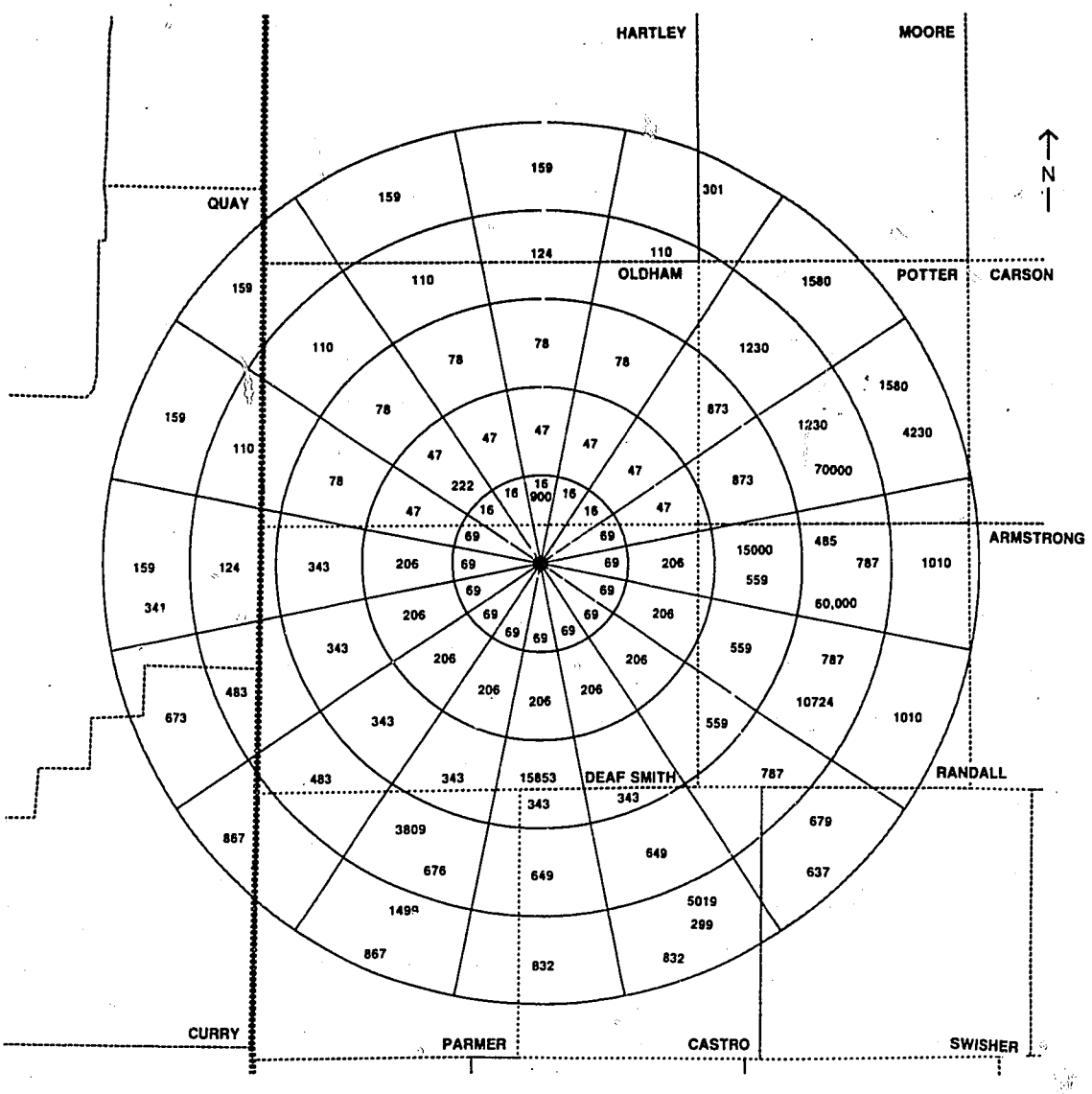

Figure 4-1. Deaf Smith County Site Population Distribution

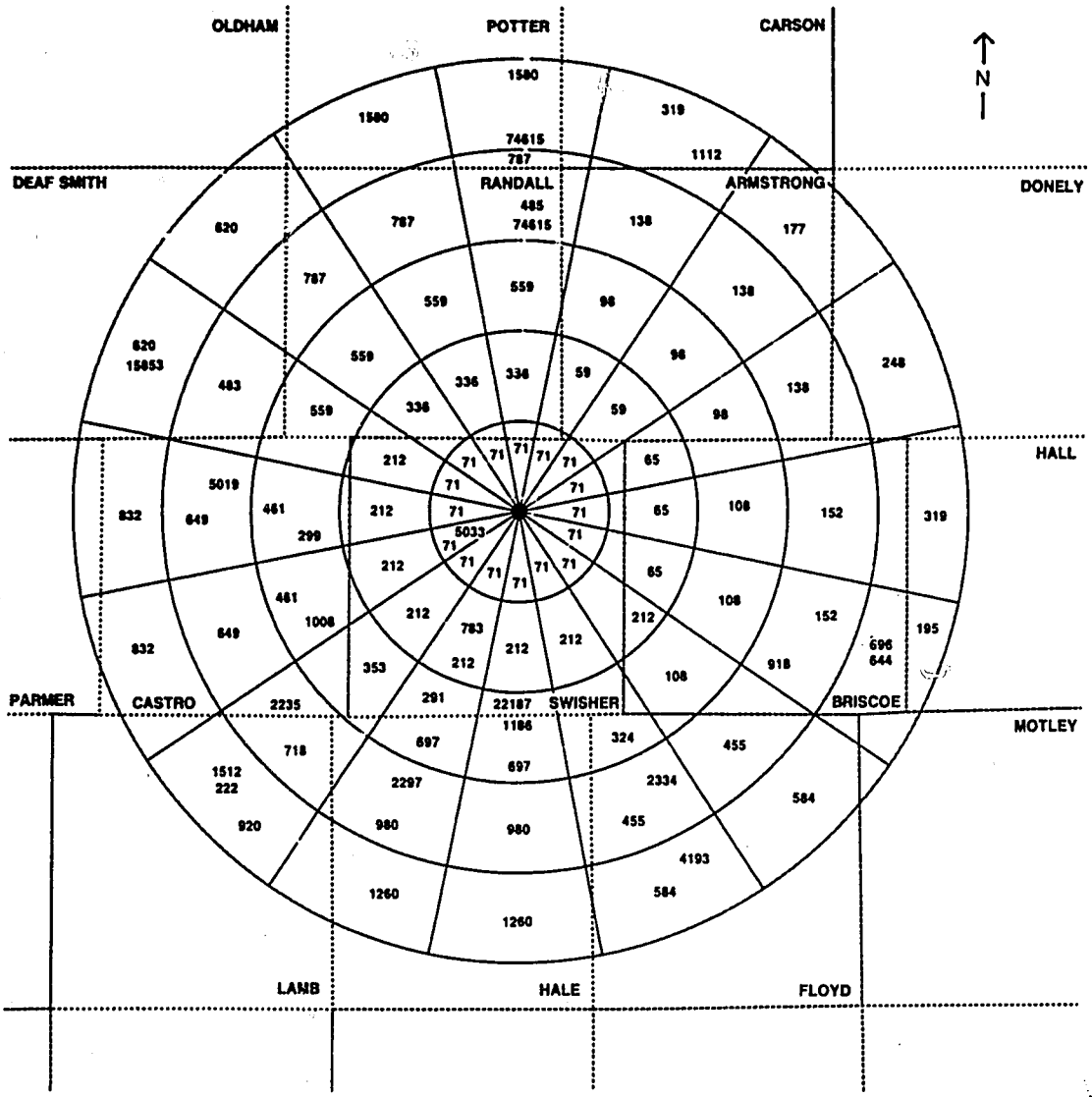

Figure 4-2. Swisher County Site Population Distribution

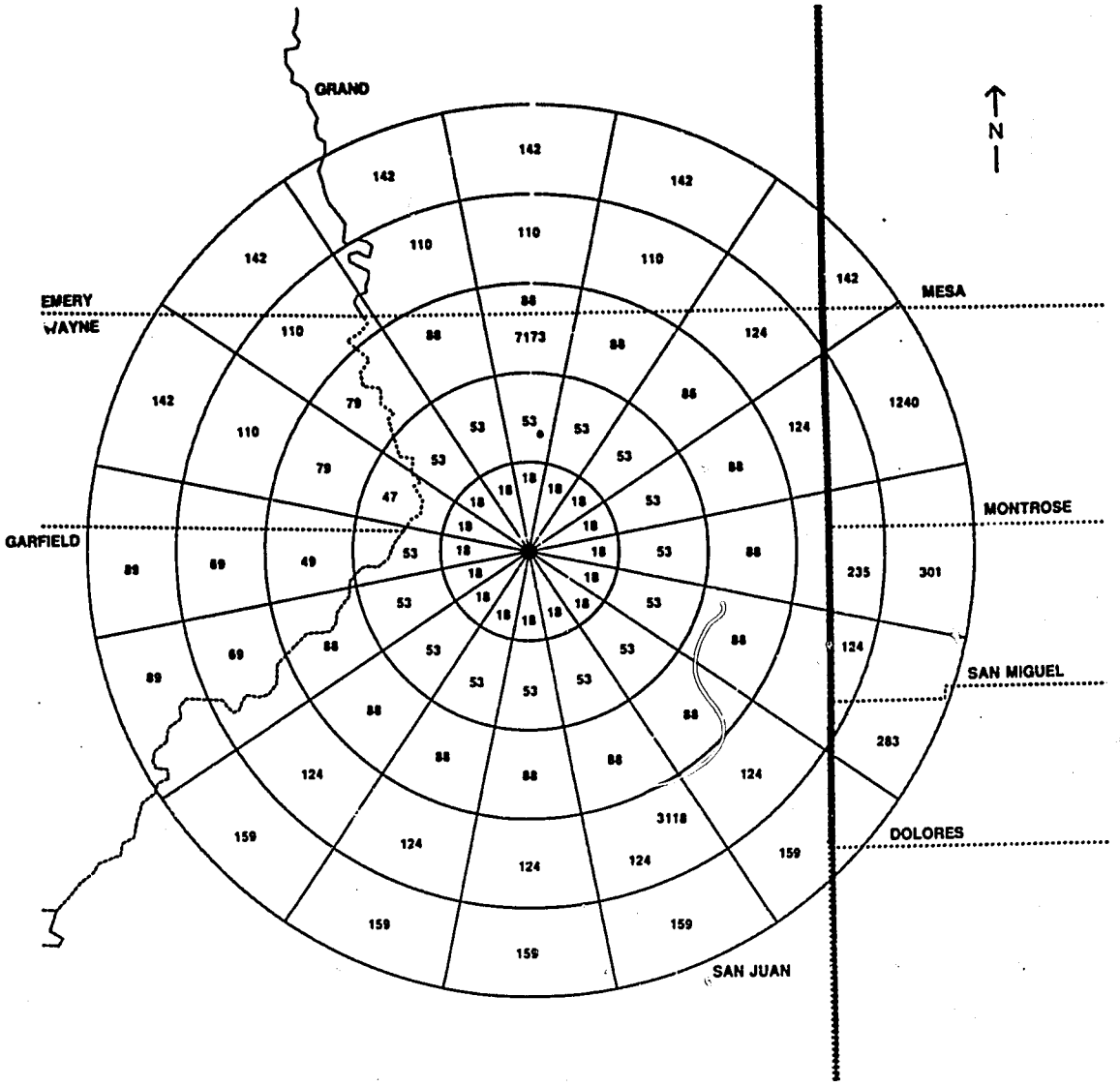

Figure 4-3. Utah Site Population Distribution

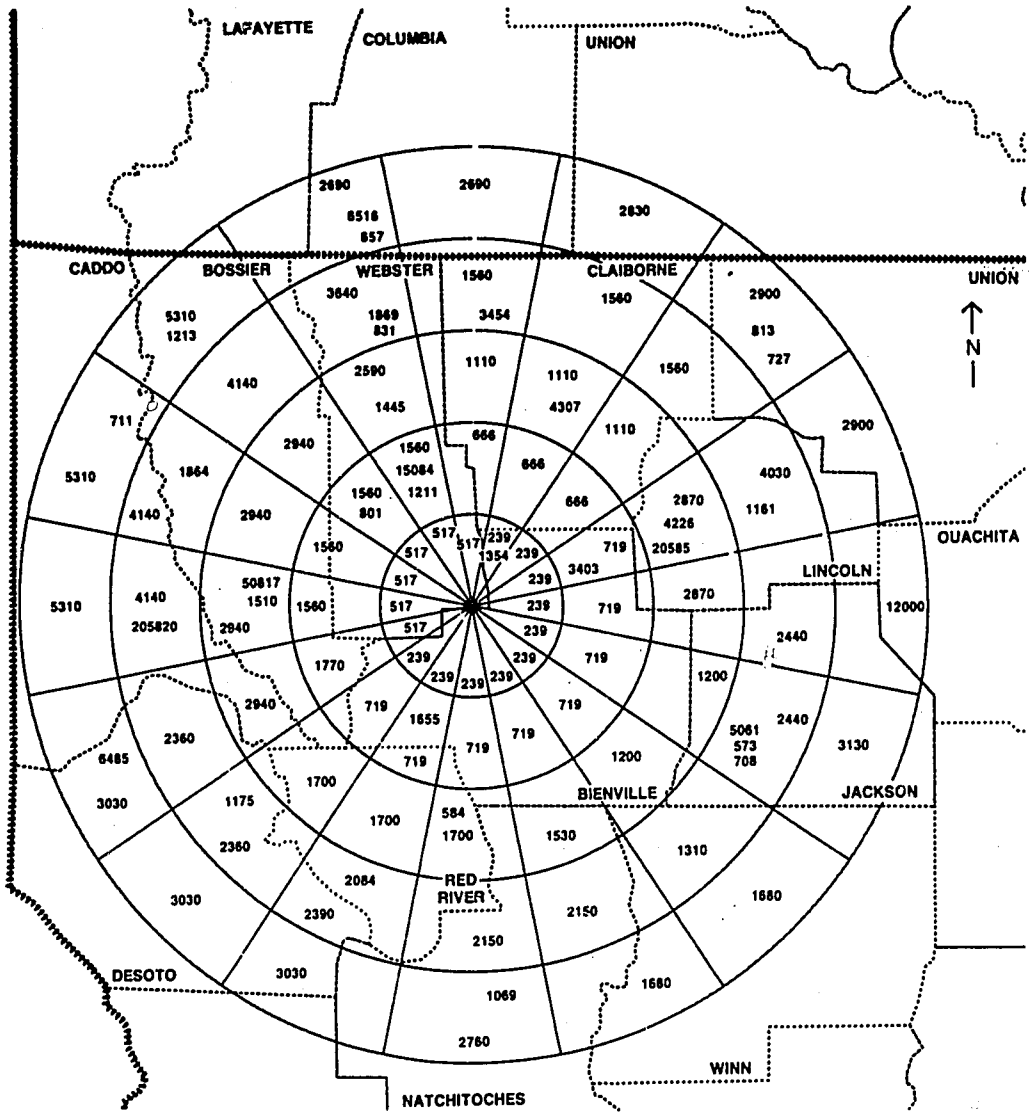

Figure 4-4. Vacherie Dome Site Population Distribution

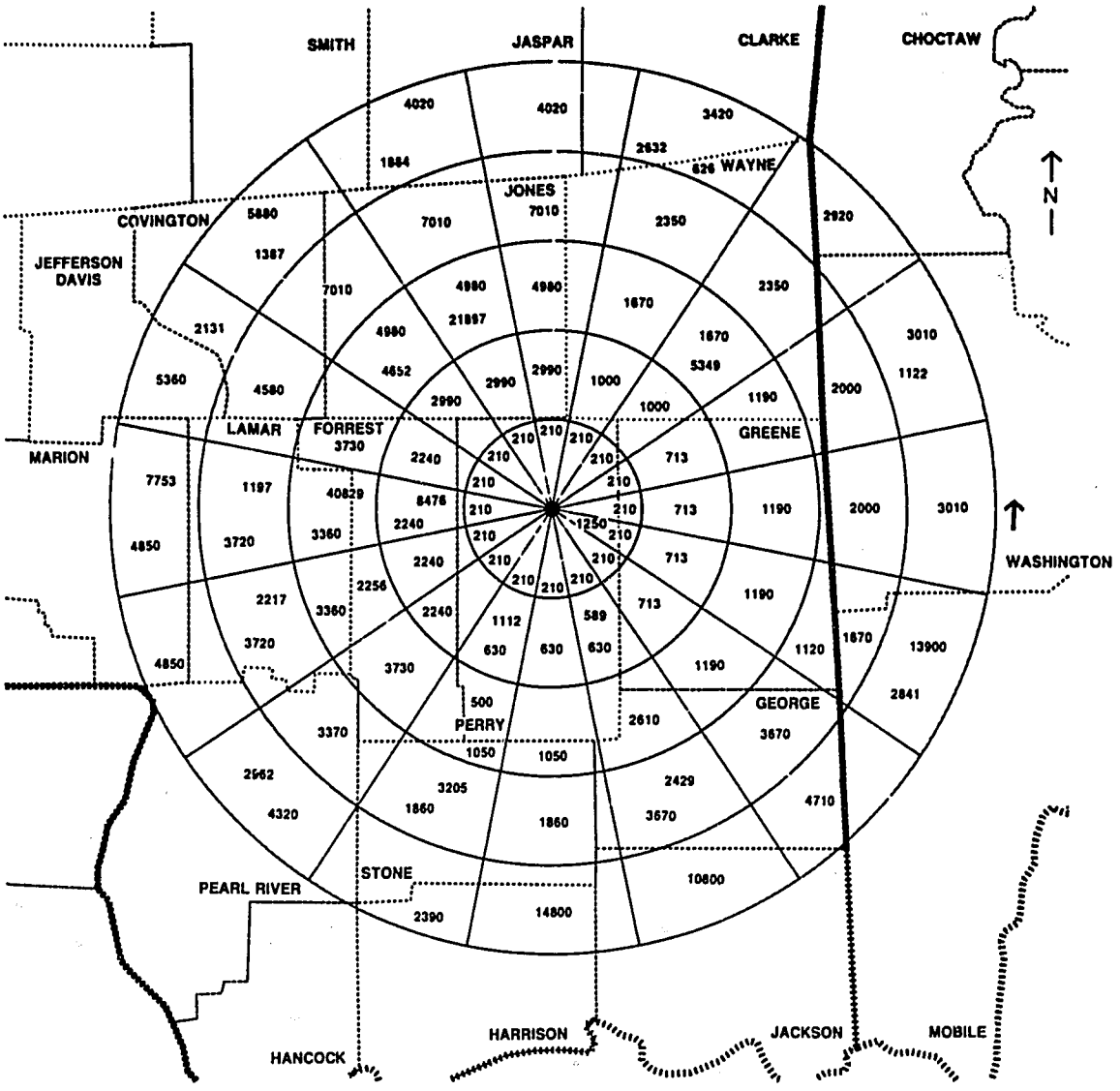

Figure 4-5. Richton Dome Site Population Distribution

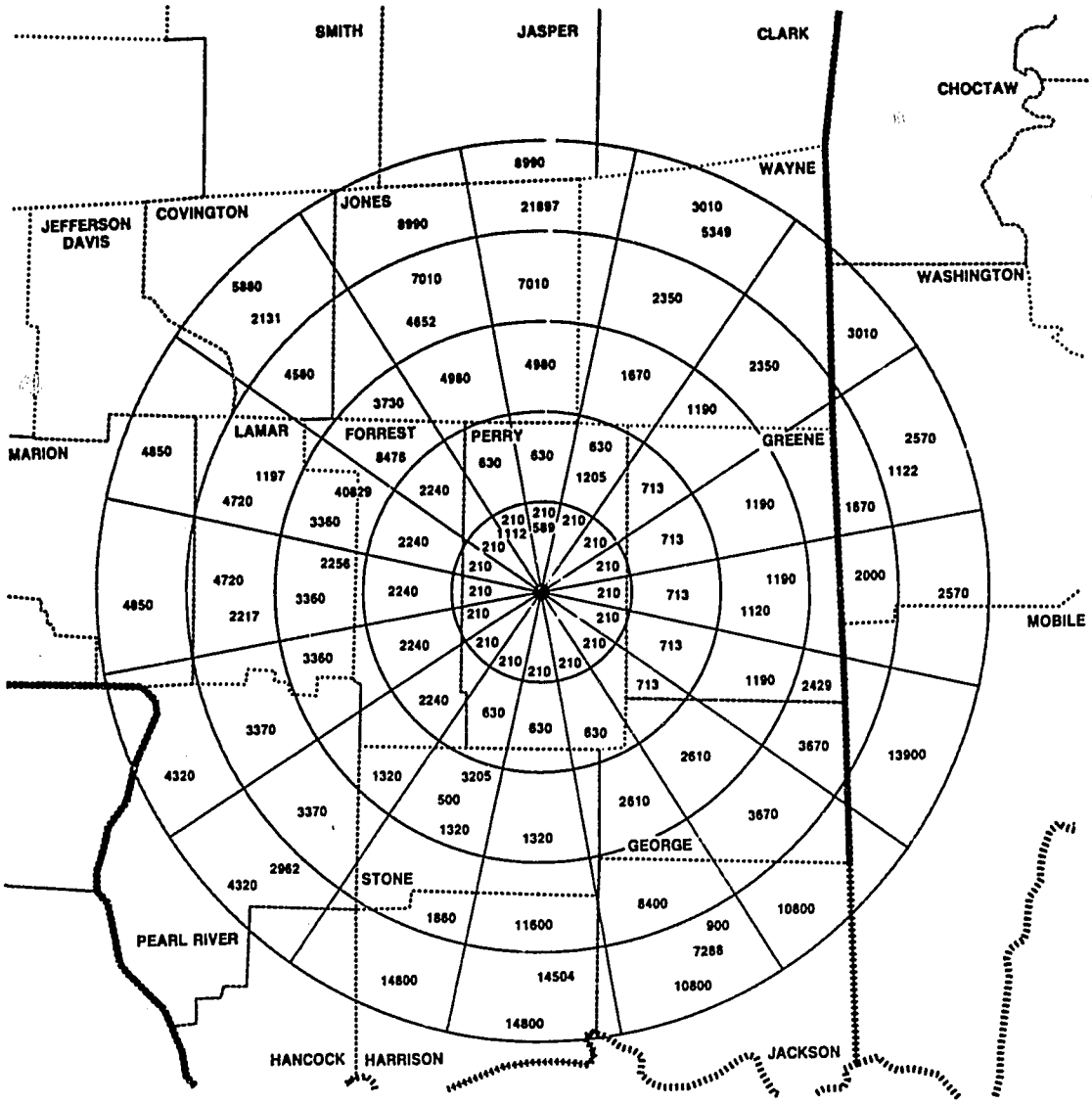

Figure 4-6. Cypress Creek Dome Site Population Distribution

1. PABLM is run from inputs stated in Section 3.1.1. The output is in the form of dose to an individual organ by food type.

2. The doses to the organs are combined by the method discussed previously.[23] The result is a total dose contribution to one person for each different food type.

3. The total dose per person by food type value is multiplied by the "affected population" parameter (see Section 3.1.1). The resulting value is the population dose attributed to that food type. This assessment is only concerned with the dose to the people living around the site area, the affected population values never exceed the total population values documented in the demography section.

4. The total population dose is calculated. The contributions from each food type are summed to arrive at a total dose.

In the case of the inhalation and submersion doses, ISDOSE is capable of receiving the population parameters in the form of the population distribution grids. An additional input into this assessment is the wind direction frequency for the site, shown in Table 4-1. This parameter determines what fraction of the time the radioactive emissions are carried toward the various directions. These values are annual averages for the four states listed in Table 4-1. Also included in this analysis as inputs are the five annular χ/Q values, which replace the maximum χ/Q value used in assessing the maximum individual case. All other inputs remain the same. The method by which the program assesses the population doses is as follows:

1. The exposure to one person in a segment of the population grid is calculated by multiplying the release rate by the χ/Q for the annulus the segment is in and then multiplying by the dose factors and other factors as done for the maximum exposed individual case (see Section 3.1.2).

2. The population dose is calculated for the segment by multiplying the dose to one person by the population of the segment.

3. The total population dose is found by summing the contributions of all of the segments of the grids.

4.3 RESULTS

Table 4-2 shows the population dose resulting from the preclosure radiological releases. The highest doses are found at the Vacherie Dome site, where the greatest population exists. The lowest doses are seen at the Deaf Smith and Swisher County sites, mainly because of the better dispersion characteristics at those two sites.

Table 4-1. Wind Direction Frequency

Direction	Texas	Utah	Mississippi	Louisiana
N	0.19	0.077	0.09	0.150
NNE	0.11	0.043	0.07	0.056
NE	0.11	0.084	0.06	0.041
ENE	0.06	0.064	0.04	0.034
E	0.06	0.073	0.03	0.035
ESE	0.03	0.046	0.04	0.037
SE	0.04	0.056	0.07	0.046
SSE	0.04	0.036	0.06	0.038
S	0.08	0.063	0.06	0.073
SSW	0.05	0.048	0.06	0.038
SW	0.04	0.040	0.06	0.033
WSW	0.02	0.025	0.04	0.032
W	0.03	0.044	0.04	0.060
WNW	0.02	0.032	0.04	0.065
NW	0.05	0.056	0.07	0.092
NNW	0.07	0.042	0.11	0.080

Table 4-2. Population 50-Year Dose Commitment

Site	Exposure Pathway Dose, mrem			Total[a]
	Inhalation	Submersion	Ingestion	
		Construction		
Deaf Smith	1.04	1.46×10^{-3}	2.0×10^{4}	2.0×10^{4}
Swisher	2.04	2.87×10^{-3}	2.2×10^{4}	2.2×10^{4}
Utah	4.19	5.90×10^{-3}	2.2×10^{4}	2.2×10^{4}
Vacherie	3.24×10^{1}	4.56×10^{-6}	1.4×10^{5}	1.4×10^{5}
Richton	2.66×10^{1}	3.75×10^{-2}	1.1×10^{5}	1.1×10^{5}
Cypress Creek	2.67×10^{1}	8.70×10^{-1}	1.1×10^{5}	1.1×10^{5}
		Operation		
Deaf Smith	7.33	4.24×10^{2}	3.9×10^{5}	3.9×10^{5}
Swisher	1.45×10^{1}	8.41×10^{2}	4.1×10^{5}	4.1×10^{5}
Utah	2.49×10^{1}	1.21×10^{3}	2.5×10^{5}	2.5×10^{5}
Vacherie	1.92×10^{2}	9.39×10^{3}	2.0×10^{6}	2.0×10^{6}
Richton	1.58×10^{2}	7.71×10^{3}	1.9×10^{6}	1.9×10^{6}
Cypress Creek	1.59×10^{2}	7.75×10^{3}	1.9×10^{6}	1.9×10^{6}

(a) This is a 50-year dose commitment from exposure to an 8-year release of radionuclides during construction and a 26-year release of radionuclides during operation of the repository.

5.0 ACCIDENT CALCULATIONS

Like the population dose assessment, the assessment of doses resulting from accidental releases of radionuclides is not required by the regulations. However, the analysis results will give a greater insight into repository impacts on the surrounding area. In the case of this analysis, five accident scenarios based on earlier analyses of repository operations[1,3] were developed:

- Spent Fuel Shaft Drop - In this scenario, six pressurized-water reactor (PWR) fuel elements, enclosed in a sealed canister and container, are dropped down the waste emplacement shaft. The fission gases and particulates are released. Most of the particulates are trapped in high efficiency particulate air (HEPA) filters. The emission is from ground level.

- Commercial High-Level Waste (CHLW) Shaft Drop - In this scenario, one package of vitrified waste containing 9.8 metric tons of uranium (MTU) is dropped down the emplacement shaft. Particulates are released; however, most are trapped by HEPA filters. Although vitrified waste was not considered a waste form for the routine emissions, the accident was analyzed because the repository may receive CHLW and/or defense high-level waste (DHLW). The CHLW case is analyzed because it is more severe than the DHLW case. The emission is from ground level.

- Spent Fuel Handling Accident - For this case, 16 PWR spent fuel assemblies in a railcar cask are crushed by another cask. It is assumed that 30 percent of the void gases are released into the handling facility and then to the environment through ventilation. This emission is from an elevated release point (61 meters).

- Remote-Handled Transuranic (RH-TRU) Waste Shaft Drop - In this scenario, 12 drums of RH-TRU are dropped down the emplacement shaft and burst. It is assumed that 20 percent of the material is released after passing through HEPA filters. The release is from ground level.

- Contact-Handled Transuranic (CH-TRU) Waste Puncture Accident - In this case, a CH-TRU drum is punctured and radioactive material is released. This release occurs in the waste handling facility, so the release is from an elevated point.

5.1 DOSE ASSESSMENT

The first inputs to the dose assessment are the source terms generated from each of the five accident scenarios. Tables 5-1 through 5-5 give the expected releases to the environment from the five accidents. Appendix B gives an explanation of these source terms and their origins.

Table 5-1. Release From Shaft Drop of Spent Fuel

Radionuclide	Release, Ci	Radionuclide	Release, Ci
^{3}H	9.0	^{238}Pu	6.0×10^{-6}
^{14}C	6.0×10^{-2}	^{239}Pu	8.7×10^{-7}
^{85}Kr	6.0×10^{3}	^{240}Pu	1.4×10^{-6}
^{90}Sr	2.0×10^{-4}	^{241}Pu	2.1×10^{-6}
^{90}Y	2.0×10^{-4}	^{241}Am	4.8×10^{-6}
^{129}I	9.0×10^{-3}	^{244}Cm	2.7×10^{-6}

Table 5-2. Release From Shaft Drop of Commercial High-Level Waste

Radionuclide	Release, Ci	Radionuclide	Release, Ci
^{90}Y	3.9×10^{-4}	^{154}Eu	3.6×10^{-5}
^{90}Sr	3.9×10^{-4}	^{238}Pu	5.6×10^{-7}
^{106}Ru	4.4×10^{-5}	^{239}Pu	1.3×10^{-8}
^{125}Te	4.8×10^{-6}	^{240}Pu	5.2×10^{-8}
^{134}Cs	8.0×10^{-5}	^{241}Pu	6.4×10^{-6}
^{137}Cs	6.0×10^{-4}	^{241}Am	5.2×10^{-6}
^{144}Ce	2.0×10^{-5}	^{244}Cm	4.4×10^{-5}

Table 5-3. Release From Spent Fuel Handling Accident

Radionuclide	Release, Ci
^{3}H	5.4
^{14}C	3.6×10^{-2}
^{85}Kr	3.6×10^{3}
^{129}I	5.4×10^{-3}

Table 5-4. Release From Shaft Drop of Remote-Handled Transuranic Waste

Radionuclide	Release, Ci	Radionuclide	Release, Ci
^{3}H	2.5×10^{-1}	^{238}Pu	1.1×10^{-9}
^{14}C	4.4×10^{-4}	^{239}Pu	7.2×10^{-11}
^{54}Mn	8.1×10^{-8}	^{240}Pu	1.5×10^{-10}
^{60}Co	1.6×10^{-6}	^{241}Pu	3.6×10^{-8}
^{63}Ni	1.6×10^{-7}	^{241}Am	1.4×10^{-10}
^{90}Sr	1.2×10^{-8}	^{242}Cm	2.0×10^{-9}
^{95}Nb	8.2×10^{-8}	^{244}Cm	1.4×10^{-9}
^{137}Cs	1.9×10^{-8}		

Table 5-5. Release From Contact-Handled Transuranic Waste Puncture Accident

Radionuclide	Release, Ci	Radionuclide	Release, Ci
^{3}H	6.3×10^{-6}	^{134}Cs	1.8×10^{-12}
^{14}C	1.6×10^{-10}	^{137}Cs	1.4×10^{-12}
^{60}Co	6.2×10^{-13}	^{238}Pu	8.2×10^{-12}
^{90}Sr	9.2×10^{-13}	^{239}Pu	5.4×10^{-13}
^{95}Nb	1.1×10^{-11}	^{240}Pu	1.1×10^{-12}
^{106}Ru	2.8×10^{-10}	^{241}Pu	2.7×10^{-10}
^{129}I	1.6×10^{-4}		

For the population dose assessment resulting from accidental releases, it is assumed that the release is directed to the three adjacent sectors (wind directions) with the greatest total population. This assumption represents the maximum number of people who could be exposed by release.

The next inputs to the analysis are the dispersion characteristics for the sites. As directed by the U.S. Nuclear Regulatory Commission[30,31], the assumed meteorological conditions are a Pasquill stability class of F and a wind speed of 1.0 m/s. This assumption represents a poor dispersion condition and, therefore, a bounding situation. Using the same method as discussed in Chapter 2, the χ/Q values for both ground level and 61-meter releases are calculated. The results are shown in Table 5-6.

Table 5-6. Calculated χ/Q Values for Accident Conditions

Ground-Level Release		61-Meter Release	
Distance, m	χ/Q, s/m^3	Distance, m	χ/Q, s/m^3
240	8.85×10^{-3}	240	0.0
8,045	3.15×10^{-5}	8,045	1.16×10^{-5}
24,135	8.51×10^{-6}	24,135	5.34×10^{-6}
40,225	4.63×10^{-6}	40,225	3.31×10^{-6}
56,135	3.18×10^{-6}	56,135	2.40×10^{-6}
72,405	2.41×10^{-6}	72,405	1.88×10^{-6}
Maximum χ/Q	8.85×10^{-3}	Maximum χ/Q	1.30×10^{-5}

The method for the dose assessment is the same as for the routine releases except for one significant change. The exposure from the ingestion of contaminated food is ignored. It is assumed that all foodstuffs grown in the area affected by the accidental release will be quarantined if necessary to avoid significant population doses. That is to say, these foodstuffs will be collected and surveyed for signs of contamination before being released for consumption. Therefore, this pathway will be eliminated.

5.2 RESULTS

The assessment of the inhalation and submersion pathways is done by using the ISDOSE code. Both maximum individual doses and population doses are calculated. The results are 50-year dose commitments attributed to the accidental release. Table 5-7 shows the resulting dose equivalents for the five

Table 5-7. 50-Year Dose Commitments From Accidental Releases

Site	Accident Scenario				
	Spent Fuel Drop	CHLW Drop	Spent Fuel Handling	RH-TRU Drop	CH-TRU Puncture
Maximum Individual, mrem					
All Sites	4.68×10^{1}	2.74	3.98×10^{-2}	3.10×10^{-3}	2.07×10^{-9}
Population, man-mrem					
Deaf Smith	2.99×10^{3}	1.75×10^{2}	1.29×10^{3}	1.98×10^{-1}	6.70×10^{-5}
Swisher	2.40×10^{3}	1.41×10^{2}	1.05×10^{3}	1.59×10^{-1}	5.47×10^{-5}
Utah	1.64×10^{2}	9.63	6.61×10^{1}	1.09×10^{-2}	3.44×10^{-6}
Vacherie	5.91×10^{3}	3.64×10^{2}	2.47×10^{3}	3.91×10^{-1}	1.29×10^{-4}
Richton	2.86×10^{3}	1.67×10^{2}	1.14×10^{3}	1.89×10^{-1}	5.95×10^{-5}
Cypress Creek	2.68×10^{3}	1.57×10^{2}	1.05×10^{3}	1.77×10^{-1}	5.49×10^{-5}

accident scenarios analyzed. The results of the maximum exposed individual analysis are the same for all sites since the same meteorology is assumed for all sites and population variations do not show up in this analysis. Table 5-8 shows the nuclides that contribute significantly to the total dose. The highest dose is from the drop of spent fuel down the shaft and is mainly due to the krypton in the spent fuel. The lowest dose result is from the CH-TRU waste puncture accident.

Table 5-8. Critical Nuclides in Accident Assessment

Inhalation	Submersion
Spent Fuel Drop	
^{129}I	^{85}Kr
^{238}Pu	
^{241}Pu	
^{241}Am	
(4%)	(96%)
CHLW Drop	
^{241}Am	^{134}Cs
^{244}Cm	^{154}Eu
(~100%)	(~0%)
Spent Fuel Handling	
^{3}H	^{85}Kr
^{129}I	
(1%)	(99%)
RH-TRU Drop	
^{3}H	^{60}Co
(~100%)	(~0%)
CH-TRU Puncture	
^{238}Pu	^{129}I
^{241}Pu	^{95}Nb
	^{134}Cs
(~100%)	(~0%)

6.0 SUMMARY AND CONCLUSIONS

The results of these analyses indicate that a high-level nuclear waste repository placed at any one of these sites can comply with preclosure radiological standards. The concentration-to-maximum permissible concentration (MPC) ratio sum, a U.S. Nuclear Regulatory Commission-regulated parameter, is only 5 percent of the limit established in the standards for the bounding case. This ratio is for the Utah sites, where the worst dispersion characteristics occur, and would be even lower at the other sites.

In comparing calculated doses with the U.S. Environmental Protection Agency dose limitation of 25 mrem/yr, the largest annual dose is 1.3 mrem during construction and 1.8 mrem during operation, both at the Utah site. The doses at the other sites are all less than 1.0 mrem/yr to the maximum exposed individual. In the population dose assessments, the doses are highest at the Vacherie Dome site and lowest at the Deaf Smith County site (during construction) and the Utah site (during operation).

For the five accident scenarios analyzed, the greatest dose is from the shaft drop of spent fuel, 4.68×10^{1} mrem, while the smallest dose is from the puncture of contact-handled transuranic waste, 2.07×10^{-9} mrem. The highest population doses from accidents occur at Vacherie Dome and the lowest at the Utah site.

In the case of all the assessments documented in this report, many degrees of conservatism were entered into the parameters. It is very likely that the actual releases and doses will be lower than the values reported here.

7.0 REFERENCES

(1) U.S. Department of Energy, 1980. Final Environmental Impact Statement, Management of Commercially Generated Radioactive Waste, Vols. I to III, DOE/EIS-0046F, Washington, DC.

(2) Nuclear Assurance Corporation, 1981. Underwater Nuclear Fuel Disassembly and Rod Storage, DOE/ET-47912, prepared for U.S. Department of Energy, Washington, DC.

(3) Battelle's Pacific Northwest Laboratories, 1979. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, prepared for U.S. Department of Energy, Washington, DC.

(4) Smith, R. I., G. J. Konzek, and W. E. Kennedy, Jr., 1978. Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station, NUREG/CR-0130, prepared by Battelle's Pacific Northwest Laboratories for U.S. Nuclear Regulatory Commission, Washington, DC.

(5) INTERA Environmental Consultants, Inc., 1983. DACRIN: A Computer Program for Calculating Organ Dose From Acute or Chronic Radionuclide Inhalation, ONWI-431, prepared for Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

(6) National Oceanic and Atmospheric Administration, 1975a. Wind Distribution by Pasquill Stability Classes - Star Program, Jackson, MS, 1970-1974, National Climatic Center, Environmental Data Service, U.S. Department of Commerce, Asheville, NC.

(7) National Oceanic and Atmospheric Administration, 1975b. Wind Distribution by Pasquill Stability Classes - Star Program, Shreveport, LA, 1970-1974, National Climatic Center, Environmental Data Service, U.S. Department of Commerce, Asheville, NC.

(8) NUS Corporation, 1982. Area Environmental Characterization Report of the Dalhart and Palo Duro Basins in the Texas Panhandle, Vol. II, Palo Duro Basin, ONWI-102(2), prepared for Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

(9) INTERA Environmental Consultants, Inc., 1983. PABLM: A Computer Code to Compute Accumulated Radiation Doses From Radionuclides Transported to Aquatic and Terrestrial Pathways in the Biosphere, ONWI-446, prepared for Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

(10) International Commission on Radiological Protection, 1959. "Report of Committee II of the ICRP on Permissible Dose for Internal Radiation," Annals of the ICRP, Publication 2, Pergamon Press, Oxford, England.

(11) U.S. Department of Agriculture, 1985. Food Consumption, Prices, and Expenditures, 1963-1983, Washington, DC.

(12) Utah Crop and Livestock Reporting Service, 1979. Utah Agricultural Statistics, 1978, Utah State Department of Agriculture, Salt Lake City, UT.

(13) Reiling, S. D., and F. H. Wiegman, 1979. Louisiana Agricultural Economic Trends and Current Status, Louisiana State University and Agricultural and Mechanical College, Baton Rouge, LA.

(14) Fielder, L. L. Jr., and B. A. Nelson, 1983. Agricultural Statistics and Prices for Louisiana, 1976-1982, Department of Agricultural Economics and Agribusiness, Center for Agricultural Sciences and Rural Development, Louisiana State University, Baton Rouge, LA.

(15) Texas Crop and Livestock Reporting Service, 1984a. 1983 Texas Vegetable Statistics, Texas Department of Agriculture, Austin, TX.

(16) Texas Crop and Livestock Reporting Service, 1984b. 1983 Texas Livestock, Dairy and Poultry Statistics, Texas Department of Agriculture, Austin, TX.

(17) Texas Crop and Livestock Reporting Service, 1984c. 1983 Texas Field Crop Statistics, Texas Department of Agriculture, Austin, TX.

(18) Texas Crop and Livestock Reporting Service, 1985. 1984 Texas Small Grain Statistics, Texas Department of Agriculture, Austin, TX.

(19) Mississippi Department of Agriculture and Commerce and U.S. Department of Agriculture Statisical Reporting Service, 1983. Mississippi Agricultural Statistics, 1981-1982, Mississippi Crop and Livestock Reporting Service Supplement Number 17, Jackson, MS.

(20) Cember, H., 1983. Introduction to Health Physics, Pergamon Press, Oxford, England.

(21) International Commission on Radiological Protection, 1978-1982. "Limits for Intakes of Radionuclides by Workers," Annals of the ICRP, ICRP Publication 30, Pergamon Press, Oxford, England.

(22) Kocher, D. C., 1983. "Dose-Rate Conversion Factors for External Exposure to Photons and Electrons," Health Physics, Vol. 45, No. 3, pp. 665-686.

(23) International Commission on Radiological Proection, 1977. "Recommendations of the International Commission on Radiological Protection," Annals of the ICRP, Publication 26, Pergamon Press, Oxford, England.

(24) Fletcher, J. F., and W. L. Dotson, 1971. HERMES - A Digital Computer Code for Estimating Regional Radiological Effects from the Nuclear Power Industry, HEDL-TME-71-168, Hanford Engineering Development Laboratory, Richland, WA.

(25) SAS Institute, Inc., 1981. SAS/GRAPH User's Guide, Cary, NC.

(26) Bechtel Group Inc., 1982. Environmental Characterization Report for the Paradox Basin Study Region, Utah Study Areas, ONWI-144, prepared for Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

(27) Bechtal Group Inc., 1982a. Environmental Characterization Report for the Gulf Interior Region, Mississippi Study Area, ONWI-193, prepared for Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

(28) Bechtel Group Inc., 1982b. Environmental Characterization Report for the Gulf Interior Region, Louisiana Study Area, ONWI-192, prepared for Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

(29) Bureau of the Census, 1983. County and City Data Book, 10th edn., a statistical abstract supplement, U.S. Department of Commerce, Washington, DC.

(30) U.S. Nuclear Regulatory Commission, 1974a. "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Pressurized Water Reactors," Regulatory Guide 1.4, Washington, DC.

(31) U.S. Nuclear Regulatory Commission, 1974b. "Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors," Regulatory Guide 1.25, Washington, DC.

8.0 STATUTES AND REGULATIONS

10 CFR Part 20, Standards for Protection Against Radiation.

10 CFR Part 60, Disposal of High-Level Radioactive Wastes in Geologic Repositories; Technical Criteria.

10 CFR Part 960, Nuclear Waste Policy Act of 1982; General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories; Final Siting Guidelines.

40 CFR Part 190, Environmental Radiation Protection Standards for Nuclear Power Operations.

40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule.

APPENDIX A

GENERAL GUIDELINES FOR THE RECOMMENDATION OF SITES FOR
THE NUCLEAR WASTE REPOSITORIES;
FINAL SITING GUIDELINES

The title page only of this document is printed here; please note that these are the Final Siting Guidelines published on December 6, 1984.

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December 6, 1984

Part III

Department of Energy

10 CFR Part 960

Nuclear Waste Policy Act of 1982; General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories; Final Siting Guidelines

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Date June 28, 1985

To S. J. Basham

From J. J. Mayberry

Subject Radionuclide Emission Rates for Preclosure Radiological Calculations for Final EA

This memo revises and replaces my June 5, 1985 memo on the preclosure radiological emission rates to be used in the final EA calculations. The changes reflect comments received from you and others regarding the construction and operational sourceterms.

Construction Radionuclide Emissions

GEIS, Volume 1, Section 5.4.8 shows an annual estimate of ^{220}Rn and ^{222}Rn released from the mining of 30 million metric tons of salt. The values are based on a period of eight years for mining (from DOE/ET/0028, Figure 7.4.18). Therefore, the total amount of natural radionuclides released by mining the salt is eight times the annual value presented in GEIS. In the final EA, the release of the natural radionuclides will be over 34 years (eight years of construction and 26 years of operation). Therefore, the annual release would be 1/34 of the total release. This value is used since excavation of the salt will extend past the eight years of construction and radionuclides will continue to emanate from the excavated salt pile.

Table 1 shows the expected release of natural radionuclides. The values shown for ^{220}Rn and ^{222}Rn are those found in GEIS. The remaining radionuclides represent all of the radon and thoron daughters. Some of these radionuclides, which were excluded in the release documented in GEIS, were considered significant to our assessment. The release values for the additional radionuclides were determined assuming an equilibrium between the radon and its daughters of 1 to 1. This assumption considers all daughters and results in the maximum release possible and therefore bounds the release. For the purposes of the radiological assessments, the contributions of the short-lived nuclide (half-lives less than one minute) are assumed to be zero for the inhalation and ingestion pathways.

Table 1. Construction Radionuclide Releases

Radionuclide	GEIS Annual Release (Ci)	EA Total Release (Ci)	EA Annual Release (Ci)
^{222}Rn	1.3×10^{-3}	1.0×10^{-2}	2.9×10^{-4}
^{218}Po	-	1.0×10^{-2}	2.9×10^{-4}
^{214}Pb	-	1.0×10^{-2}	2.9×10^{-4}
^{214}Bi	-	1.0×10^{-2}	2.9×10^{-4}
^{214}Po	-	1.0×10^{-2}	2.9×10^{-4}
^{210}Pb	-	1.0×10^{-2}	2.9×10^{-4}
^{210}Bi	-	1.0×10^{-2}	2.9×10^{-4}
^{210}Po	-	1.0×10^{-2}	2.9×10^{-4}
^{220}Rn	9.3×10^{-4}	7.4×10^{-3}	2.2×10^{-4}
^{216}Po	-	7.4×10^{-3}	2.2×10^{-4}
^{212}Pb	-	7.4×10^{-3}	2.2×10^{-4}
^{212}Bi	-	7.4×10^{-3}	2.2×10^{-4}
^{212}Po	-	4.7×10^{-3}	1.4×10^{-4}
^{208}Tl	-	2.7×10^{-3}	7.8×10^{-5}

Accident Radionuclide Emissions

The most credible bounding accident that can happen to contact-handled TRU is the puncture of the drum and subsequent release of the drum's contents. In GEIS, Table 5.4.24, it was shown that each incident would release to the atmosphere:

Table 2. CH-TRU Puncture Accident Release

^{3}H	6.3×10^{-6}	Curies
^{14}C	1.6×10^{-10}	Curies
^{60}Co	6.2×10^{-13}	Curies
^{90}Sr	9.2×10^{-13}	Curies
^{95}Nb	1.1×10^{-11}	Curies
^{106}Ru	2.8×10^{-10}	Curies
^{129}I	1.6×10^{-4}	Curies
^{134}Cs	1.8×10^{-12}	Curies
^{137}Cs	1.4×10^{-12}	Curies
^{238}Pu	8.2×10^{-12}	Curies
^{239}Pu	5.4×10^{-13}	Curies
^{240}Pu	1.1×10^{-12}	Curies
^{241}Pu	2.7×10^{-10}	Curies

Each drum handled has a single probability of puncture of 3×10^{-5}; thus, with 202,450 drums, a total of six punctures over the facility life can be expected. This is classified as an abnormal operation.

HLW

All high-level waste arriving at the repository will be vitrified in glass. The only credible accident which would release radionuclides is a shaft drop, and clearly a shaft drop is an abnormal operation.

GEIS, Table 5.4.25, determined that an accident involving a hoist load of four canisters of 2.4 MTU* would release the quantities of radionuclides shown in Table 3. Stearns designs are for waste packages of 9.8 MTU carried one at a time on the hoist. In either case, a release scenario would be virtually identical to the original GEIS release values.

*MGDS specified 2.28 MTU.

Incidentally, the release values are for commercial HLW. Defense HLW release values are substantially lower, and thus the values in Table 3 can be considered bounding for all HLW.

Table 3. Shaft Drop Release

^{90}Y	3.9×10^{-4}	Curies
^{90}Sr	3.9×10^{-4}	Curies
^{106}Ru	4.4×10^{-5}	Curies
^{125}Te	4.8×10^{-6}	Curies
^{123}Cs	8.0×10^{-5}	Curies
^{137}Cs	6.0×10^{-4}	Curies
^{144}Ce	2.0×10^{-5}	Curies
^{154}Eu	3.6×10^{-5}	Curies
^{238}Pu	5.6×10^{-7}	Curies
^{239}Pu	1.3×10^{-8}	Curies
^{240}Pu	5.2×10^{-8}	Curies
^{241}Pu	6.4×10^{-6}	Curies
^{241}Am	5.2×10^{-6}	Curies
^{244}Cm	4.4×10^{-5}	Curies

RH-TRU

The bounding RH-TRU accident is the shaft drop of canisters carrying RH-TRU drums. In this accident, four canisters carrying three drums each drop down the mine shaft and burst. Some 20 percent of the material is released. The quantity of radionuclides released to the atmosphere for such an incident is as shown in Table 4 (from GEIS, Table 5.4.25):

Table 4. Radionuclide Emissions from TRU Hoist Drop

^{3}H	2.5×10^{-1}	Curies
^{14}C	4.4×10^{-4}	Curies
^{60}Co	1.6×10^{-6}	Curies
^{63}Ni	1.6×10^{-7}	Curies
^{90}Sr	1.2×10^{-8}	Curies
^{54}Mn	8.1×10^{-8}	Curies
^{95}Nb	8.2×10^{-8}	Curies
^{137}Cs	1.9×10^{-8}	Curies
^{238}Pu	1.1×10^{-9}	Curies
^{239}Pu	7.2×10^{-11}	Curies
^{240}Pu	1.5×10^{-10}	Curies
^{241}Pu	3.6×10^{-8}	Curies
^{241}Am	1.4×10^{-10}	Curies
^{242}Cm	2.0×10^{-9}	Curies
^{244}Cm	1.4×10^{-9}	Curies

The probability of occurrence was estimated in GEIS at 3.5×10^{-6}/year. This is clearly an abnormal event.

Spent Fuel

In this accident, GEIS (Table 5.4.22) determined the consequences if four spent fuel (PWR) assemblies dropped down the shaft. This is an abnormal operation.

Values reported in GEIS for radionuclide emissions are reported in Table 5.

The Stearn's design calls for 6 PWR assemblies to be on a hoist. For hoist failure releases, therefore, the values reported in Table 5 must be multiplied by 1.5 for the purposes of the current EA analysis.

Table 5. Spent Fuel Shaft Drop

	GEIS		EA Release
^{3}H	6	Curies	9
^{14}C	4×10^{-2}	Curies	6×10^{-2}
^{85}Kr	$4 \times 10^{+3}$	Curies	$6 \times 10^{+3}$
^{90}Sr	1×10^{-4}	Curies	2×10^{-4}
^{90}Y	1×10^{-4}	Curies	2×10^{-4}
^{129}I	6×10^{-3}	Curies	9×10^{-3}
^{137}Cs	1.5×10^{-4}	Curies	2.3×10^{-4}
^{238}Pu	4×10^{-6}	Curies	6×10^{-6}
^{239}Pu	5.8×10^{-7}	Curies	8.7×10^{-7}
^{240}Pu	9×10^{-7}	Curies	1.4×10^{-6}
^{214}Pu	1.4×10^{-4}	Curies	2.1×10^{-4}
^{241}Am	3.2×10^{-6}	Curies	4.8×10^{-6}
^{244}Cm	1.8×10^{-6}	Curies	2.7×10^{-6}

Spent Fuel Handling Accident

In this accident, the 12 PWR assemblies in a railcar cask are somehow damaged within the receiving building. Because of filtration, virtually all of the particulate is contained. This is an incident chosen to involve the greatest number of assemblies which could be affected by a single cause event.

It is assumed that 30 percent of the void gases in the pins would be released by the accident. Gaseous releases, then, can be found by multiplying the values for ^{3}H, ^{14}C, ^{85}Kr and ^{129}I by "3" in the "GEIS" column in Table 5 above (to account for 12 assemblies instead of 4) and by "0.3" (to account for release fraction).

Table 6. Spent Fuel Handling Accident Release

^{3}H	5.4	Curies
^{14}C	3.6×10^{-2}	Curies
^{85}Kr	$3.6 \times 10^{+3}$	Curies
^{129}I	5.4×10^{-3}	Curies

This is an abnormal condition.

Routine Operational Radionuclide Emissions

The routine operational release of radionuclides originates from the disassembly of spent fuel elements. Based on a study by the Nuclear Assurance Corporation, documented in DOE/ET-47912, Underwater Nuclear Fuel Disassembly and Rod Storage, 0.1 to 0.3 percent of the rods will stick in the spacers and 50 percent of those stuck rods will rupture during disassembly. In the BWIP draft EA, the conservative assumption that 1.0 percent of the rods stick and 50 percent of those rods rupture was used. This leads to a failure fraction of .005. This is the failure value to be used for the final salt EAs.

The total number of rods received in one year will vary from year to year at the repository. Based on values in ONWI-258 (CRRD), the maximum number of rods received in any one year will be 1,100,000 rods and the annual average will be 634,000 rods. This is based on 50 percent spent fuel and 50 percent CHLW. Also, the spent fuel is received in a ratio of 3 BWR assemblies to 2 PWR assemblies. Table 7 shows the maximum and average annual releases expected. The release values from the failure of one rod are from DOE/ET-0028, Technology for Commercial Radioactive Waste Management.

Table 7. Routine Operational Radionuclide Emissions

Radionuclide	Emissions from One Failed Rod (Ci)	Maximum Annual Release (Ci)	Average Annual Release (Ci)
^{3}H	5.0×10^{-3}	2.8×10^{1}	1.6×10^{1}
^{14}C	4.0×10^{-5}	2.2×10^{-1}	1.3×10^{-1}
^{85}Kr	3.0	1.7×10^{4}	9.5×10^{3}
^{129}I	5.0×10^{-6}	2.8×10^{-2}	1.6×10^{-2}

The radionuclides listed in Table 7 represent those volatile fission gases expected to be released if the cladding is ruptured. The values documented in DOE/ET-0028 assume 6.5 year old spent fuel is involved. Therefore, the values of the releases vary only slightly from what would be expected from five year old fuel, which is called for in the generic requirements. The releases documented here also assume only a fraction of the rod inventory of fission gas is released.

The maximum annual release, based on the receipt of 1.1 million rods, will be used to calculate compliance with 10 CFR 20 regulations which govern the maximum permissible concentrations which can be released to the unrestricted area. The annual release, based on the receipt of 634,000 rods, will be used for calculating the dose to the public receives over the 26 years of operation. One repository design under consideration calls for the emplacement of 100 percent spent fuel, or twice as much spent fuel as in the reference case presented here. Therefore, for the purposes of the preclosure radiological calculations, the values stated in Table 7 will be doubled. This change effects only the operational sourceterm.

The introduction of the disassembly sourceterm is in response to a comment on the draft EAs by the NRC. The routine operation sourceterm previously included in the draft EAs, where 6 rods fail per year during transportation of the fuel assemblies to the site, has been disregarded in this final analysis. This failure is considered insignificant compared to the 3,200 rods expected to fail in an average year due to disassembly. Consequently, the sourceterm for routine operational releases is very different from that in the earlier analysis.

JJM:fk

SALT EXCAVATION SOURCETERM CALCULATIONS

STEVE MAHERAS[1]

Problem

1. In order to calculate the dose equivalent to the maximum individual and the population dose equivalent from construction activities at a HLW repository, radon and thoron sourceterms must be estimated.

2. Since radon and thoron decay serially, there is a time dependence on the radon and thoron sourceterms. That is to say, the time necessary for a radionuclide to migrate from source to receptor determines to some extent the relative concentrations of the members of the series and therrefore the dose equivalent.

3. There are three possible approaches to the problem.

   a. Assume all radionuclides in the chain are released in equal activities.

   b. Calculate the time dependent sourceterm for each radionuclide in the chain, assuming only radon and thoron is released initially.

   c. Use an equilibrium constant to account for dispersion and radioactive decay of radon and thoron once released.

Models and Assumptions

1. Rn-222 and Rn-220 are liberated during salt excavation.

2. Rn-222 and Rn-220 decay while in the mine to its progeny.

3. Air in the mine is exhausted to the environment, along with Rn-222, Rn-220 and their progeny.

4. The model used is serial decay of Rn-222 through Pb-206 and Rn-220 through Tl-208.

5. The model assumes an initial deposition of Rn-222 or Rn-220 into a cohort

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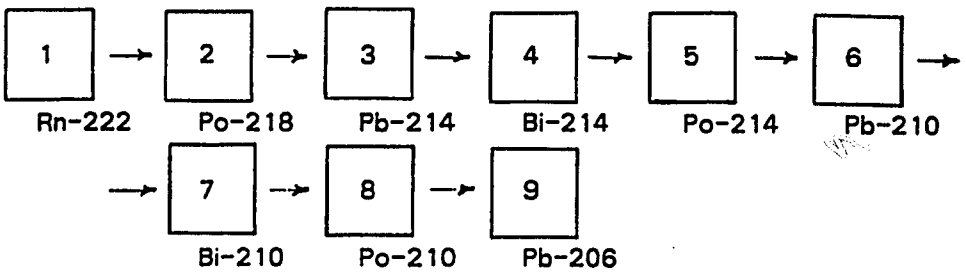
[1]The research was performed under appointment to the Nuclear Engineering, Health Physics, and Radioactive Waste Management Fellowship program administered by Oak Ridge Associated Universities for the U.S. Department of Energy.

of air which then moves out of the mine, that is to say, the initial concentration of all radionuclides except for Rn-222 and Rn-220 are zero.

Rn-222 Mathematical Treatment



Differential Equations:

$$\frac{dq_1}{dt} = -k_1 q_1$$

$$\frac{dq_2}{dt} = k_1 q_1 - k_2 q_2$$

$$\frac{dq_3}{dt} = k_2 q_2 - k_3 q_3$$

$$\frac{dq_4}{dt} = k_3 q_3 - k_4 q_4$$

$$\frac{dq_5}{dt} = k_4 q_4 - k_5 q_5$$

$$\frac{dq_6}{dt} = k_5 q_5 - k_6 q_6$$

$$\frac{dq_7}{dt} = k_6 q_6 - k_7 q_7$$

$$\frac{dq_8}{dt} = k_7 q_7 - k_8 q_8$$

$$\frac{dq_9}{dt} = k_8 q_8$$

Solution for compartment 1 is: $q_1(t) = q_1(0)e^{-k_1 t}$

Solutions for compartments 2 through 8 are of the form:

$$q_n = q_1(0) \prod_{i=1}^{n-1} k_i \sum_{i=1}^{n} \frac{e^{-k_i t}}{\prod_{i=1, i \neq j}^{n} (k_j - k_i)}$$

solution for compartment 9 is of the form:

$$q_9 = q_1(0) \prod_{i=1}^{8} k_i \sum_{i=1}^{8} \frac{e^{-k_i t}}{\prod_{i=1, i=j}^{8} (k_j - k_i)}$$

Calculations

1. All radionuclides released in equal activities: [31]

Radionuclide	Activity,Curies
Rn-222	1.0×10^{-2}
Po-218	1.0×10^{-2}
Pb-214	1.0×10^{-2}
Bi-214	1.0×10^{-2}
Po-214	1.0×10^{-2}
Pb-210	1.0×10^{-2}
Bi-210	1.0×10^{-2}
Po-210	1.0×10^{-2}

2. Time dependent release ($q_1(0) = 1.0 \times 10^{-2}$)

RN	Activity, Curies 1.0hr	2.0hr	5.0hr	24.0hr
Rn-222	9.9×10^{-3}	9.9×10^{-3}	9.6×10^{-3}	8.3×10^{-3}
Po-218	9.9×10^{-3}	9.8×10^{-3}	9.6×10^{-3}	8.3×10^{-3}
Pb-214	7.6×10^{-3}	9.5×10^{-3}	9.8×10^{-3}	8.5×10^{-3}
Bi-214	4.8×10^{-3}	8.4×10^{-3}	9.7×10^{-3}	8.4×10^{-3}
Po-214	4.8×10^{-3}	8.4×10^{-3}	9.7×10^{-3}	8.4×10^{-3}
Pb-210	5.3×10^{-8}	7.9×10^{-8}	5.3×10^{-7}	8.3×10^{-7}
Bi-210	1.1×10^{-7}	1.1×10^{-7}	1.1×10^{-7}	1.5×10^{-7}
Po-210	6.2×10^{-9}	6.4×10^{-9}	6.9×10^{-9}	9.8×10^{-9}

Time dependent release equilibrium factors:

RN	Equilibrium Factor 1.0hr	2.0hr	5.0hr	24.0hr
Rn-222	9.9×10^{-1}	9.9×10^{-1}	9.6×10^{-1}	8.3×10^{-1}
Po-218	9.9×10^{-1}	9.8×10^{-1}	9.6×10^{-1}	8.3×10^{-1}
Pb-214	7.6×10^{-1}	9.5×10^{-1}	9.8×10^{-1}	8.5×10^{-1}
Bi-214	4.8×10^{-1}	8.4×10^{-1}	9.7×10^{-1}	8.4×10^{-1}
Po-214	4.8×10^{-1}	8.4×10^{-1}	9.7×10^{-1}	8.4×10^{-1}
Pb-210	5.3×10^{-6}	7.9×10^{-6}	5.3×10^{-5}	8.3×10^{-5}
Bi-210	1.1×10^{-5}	1.1×10^{-5}	1.1×10^{-5}	1.5×10^{-5}
Po-210	6.2×10^{-7}	6.4×10^{-7}	6.9×10^{-7}	9.8×10^{-7}

3. Equilibrium Constant

The typical outdoor equilibrium ratios are 1.0/0.7/0.6/0.6 [7] for Po-218/Pb-214/Bi-214/Po-214. Therefore, if $q_1(0) = 1.0 \times 10^{-2}$, then the following activities are calculated:

Radionuclide	Activity, Curies
Rn-222	1.0×10^{-2}
Po-218	1.0×10^{-2}
Pb-214	0.7×10^{-2}
Bi-214	0.6×10^{-2}
Po-214	0.6×10^{-2}

Because this method was developed for use in determining Working Levels, it does not consider Pb-210, Bi-210, or Po-210. Using typical equilibrium constants, these ratios can be estimated at $5.3 \times 10^{-6}/1.1 \times 10^{-5}/6.2 \times 10^{-7}$ for those radionuclides respectively. If q_1 is again assumed to equal 1.0×10^{-2}, then the following activities are calculated:

Radionuclide	Activity, Curies
Rn-222	1.0×10^{-2}
Po-218	1.0×10^{-2}
Pb-214	0.7×10^{-2}
Bi-214	0.6×10^{-2}
Po-214	0.6×10^{-2}
Pb-210	5.3×10^{-6}
Bi-210	1.1×10^{-5}
Po-210	6.2×10^{-7}

Results

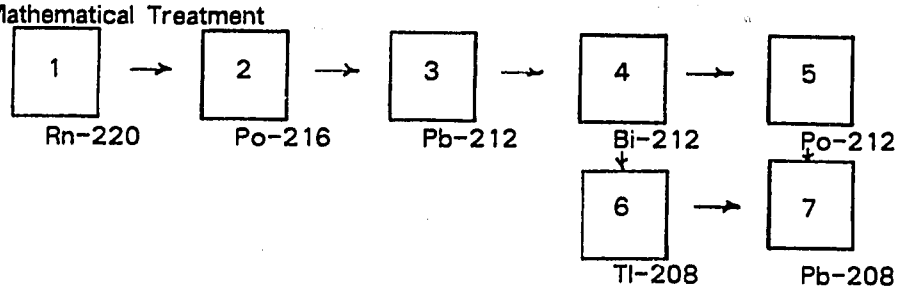
It is apparent that approach 1, all radionuclides released in equal activities, is the most conservative, i.e., it represents a worst-case scenario. This method estimates Rn-222 through Po-214 well when compared to the other methods and overestimates the remaining activities by 5 to 6 orders of magnitude.

Approaches 2 and 3 yield comparable results in a time frame of one hour. After one

hour, approach 2 becomes slightly more conservative, estimating Rn-222 through Po-214 as 1:1:1:1:1.

In summary, all approaches agree within an order of magnitude for the Rn-222 through Po-214 portion of the decay series. However, approach 1 overestimates the Pb-210 through Po-210 portion of the chain by between 5 to 6 orders of magnitude when compared to approaches 2 and 3.

Rn-220 Mathematical Treatment



Differential Equations:

$$\frac{dq_1}{dt} = -k_1 q_1$$

$$\frac{dq_2}{dt} = k_1 q_1 - k_2 q_2$$

$$\frac{dq_3}{dt} = k_2 q_2 - k_3 q_3$$

$$\frac{dq_4}{dt} = k_3 q_3 - k_4 q_4$$

$$\frac{dq_5}{dt} = (0.63)\, k_4 q_4$$

$$\frac{dq_5}{dt} = (0.36)\, k_4 q_4$$

Calculations

1. Assume all radionuclides released in equal activities: [31]

Radionuclides	Activity, Curies
Rn-220	7.4×10^{-3}
Po-216	7.4×10^{-3}
Pb-212	7.4×10^{-3}
Bi-212	7.4×10^{-3}
Po-212	4.7×10^{-3}
Tl-208	2.7×10^{-3}

2. Time dependent release ($q_1(0) = 1.5 \times 10^{-2}$)

	Activity, Curies			
RN	60s	120s	300s	3600s
Rn-220	7.0×10^{-3}	3.3×10^{-3}	3.4×10^{-4}	3.0×10^{-22}
Po-216	7.1×10^{-3}	3.3×10^{-3}	3.4×10^{-4}	3.0×10^{-22}
Pb-212	1.1×10^{-5}	1.7×10^{-5}	2.1×10^{-5}	2.0×10^{-5}
Bi-212	1.6×10^{-7}	3.3×10^{-7}	9.8×10^{-7}	1.0×10^{-5}
Po-212	1.0×10^{-7}	2.1×10^{-7}	6.3×10^{-7}	6.4×10^{-6}
Tl-208	1.8×10^{-5}	1.8×10^{-5}	1.7×10^{-5}	1.3×10^{-5}

3. Time dependent release equilibrium factors

RN	60s	120s	300s	3600s
Rn-220	0.47	0.22	2.3×10^{-2}	3.0×10^{-22}
Po-216	0.47	0.22	2.3×10^{-2}	3.0×10^{-22}
Pb-212	7.3×10^{-4}	1.1×10^{-3}	1.4×10^{-3}	1.3×10^{-3}
Bi-212	1.1×10^{-5}	2.2×10^{-5}	6.5×10^{-5}	6.7×10^{-4}
Po-212	6.7×10^{-6}	1.4×10^{-5}	4.2×10^{-5}	4.3×10^{-4}
Tl-208	1.2×10^{-3}	1.2×10^{-3}	1.1×10^{-3}	8.7×10^{-4}

4. Equilibrium constant. Assuming a 3600s decay time, equilibrium constants of $20x10^{-20}/2.0x10^{-20}/1.3x10^{-3}/6.7x10^{-4}/4.3x10^{-4}/8.7x10^{-4}$ can be calculated for Rn-220/Po-216/Pb-212/Bi-212/Po-212/Tl-208.

5. Summary

For the Rn-220 decay series, both approaches 1 and 2 yield comparable results for releases at 60s. Approach 1 then becomes more conservative by 2 to 4 orders of magnitude. However, in the time span most applicable (between 1 and 2 hours), approach 1 is more conservative by 19 orders of magnitude for Rn-220 and Po-216, while only 2 to 3 orders of magnitude more conservative for Pb-212 through Tl-208.

URANIUM MILL TAILINGS PILES

An average stabilized uranium mill tailings pile has a Rn-222 flux of 500 $pCi/m^2.s$ and an unstabilized pile has a flux of 650 pCi/m^2s [15]

Typical tailings piles are about 120 acres or 500,00 m^2 in area. Therefore, an average tailings pile would emit approximately 2.4×10^8 pCi/s of Rn-222 (2.4×10^{-4} Ci/s). Using the three approaches outlined previously:

Approach 1 - All radionuclides released in equal activities.

Radionuclide	Activity (Ci/s)
Rn-220	2.4×10^{-4}
Po-218	2.4×10^{-4}
Pb-214	2.4×10^{-4}
Bi-214	2.4×10^{-4}
Po-214	2.4×10^{-4}
Pb-210	2.4×10^{-4}
Bi-210	2.4×10^{-4}
Po-210	2.4×10^{-4}

Approach 2 – Time dependent release: (Ci/s)

RN	1 hr	2 hr	5 hr	24 hr
Rn-222	2.4×10^{-4}	2.4×10^{-4}	2.3×10^{-4}	2.0×10^{-4}
Pc-218	2.4×10^{-4}	2.4×10^{-4}	2.4×10^{-4}	2.0×10^{-4}
Pb-214	1.8×10^{-4}	2.3×10^{-4}	2.4×10^{-4}	2.0×10^{-4}
Bi-214	1.2×10^{-4}	2.0×10^{-4}	2.3×10^{-4}	2.0×10^{-4}
Po-214	1.2×10^{-4}	2.0×10^{-4}	2.3×10^{-4}	2.0×10^{-4}
Pb-210	1.3×10^{-9}	1.9×10^{-9}	5.3×10^{-9}	2.0×10^{-8}
Bi-210	2.6×10^{-9}	2.6×10^{-9}	2.6×10^{-9}	3.6×10^{-9}
Po-210	1.5×10^{-10}	1.5×10^{-10}	1.7×10^{-10}	2.4×10^{-10}

Approch 3 – Equilibrium factors

Radionuclides	Curies per second
Rn-220	2.4×10^{-4}
Po-218	2.4×10^{-4}
Pb-214	1.7×10^{-4}
Bi-214	1.4×10^{-4}
Po-214	1.4×10^{-4}
Pb-210	1.3×10^{-9}
Bi-210	2.6×10^{-9}
Po-210	1.5×10^{-10}

APPENDIX B

DEVELOPING RADIONUCLIDE EMISSION RATES

The first section of this appendix is a memo to S. J. Basham from J. J. Mayberry on June 28, 1985. It contains the source terms used in the radiological assessments associated with finalizing the draft environmental assessments. The second section is a radon emission calculation made by S. Maheras.

SALT PILE RADON SOURCETERM CALCULATION

Soil typically contains 0.6 pCi per gram of soil and releases radon at a rate of 0.42 pCi Rn-222/m^2.s. Rock salt contains approximately 0.033 pCiU/g rock salt. Assuming that rock salt releases the same fraction of Rn-222 that soil does, rock salt should release 0.023 pCi Rn-222/m^2.s. By piling rock salt on top of soil, which effectively smothers the soil release of radon, the net radon release rate is reduced by 95%.

C.1 INTRODUCTION

The ISDOSE computer code was developed at Battelle Memorial Institute for the Office of Nuclear Waste Isolation (ONWI) to calculate submersion and inhalation doses from atmospheric releases of radionuclides from a nuclear waste repository. ISDOSE can calculate doses from both normal and accidental releases. It contains two dose factor libraries: one for submersion dose factors (SDF) and one for inhalation dose factors (IDF). ISDOSE can calculate the dose for 37 different radionuclides, given the nuclides and their release quantities.

ISDOSE can calculate the dose commitment and the total dose for each of the nuclides in the input data set, and the percentage of the total dose for each of the nuclides. Tables are printed for both the annual dose from a 1-year release and a 50-year dose commitment from the total release. Only the 50-year dose commitment is printed for accident cases.

ISDOSE can be set up to calculate the dose to a given population or to the maximum individual. The population distribution input is in the form of a circular grid. A wind frequency input is required for each sector of the grid, and a χ/Q, the dispersion factor for airborne contaminants, input is required for each annuli. In a maximum individual run, the population and wind frequency for the first sector and the first annuli are set to one. A maximum exposed individual run calculates the maximum dose delivered to an individual given appropriate input.

The ISDOSE computer code has been set up to calculate inhalation and submersion doses for most preclosure releases from a nuclear repository. It will handle population and maximum exposed individual doses for both normal operations and accident cases. This report includes an in-depth discussion of its inputs, and its two libraries. The program listing, sample, input, and output are also included.

C.2 THEORY AND CALCULATIONS

The theory behind the dose equivalency calculations in ISDOSE relies on the application of inhalation and submersion dose conversion factors to calculate the dose via the inhalation and submersion pathways. The inhalation dose factor enables the calculation of a dose equivalency when the quantity of radionuclide intake is known. In the case of the submersion pathway, the dose is calculated for an exposure to an concentration of a radionuclide in air. ISDOSE manipulates the inputted data to arrive at intake and air concentration values, then applies the dose factors contained in the IDF and SDF libraries to calculate the dose.

C.2.1 Maximum Exposed Individual Dose Assessment

ISDOSE applies the following equations to calculate the dose to the maximum exposed individual:

Inhalation:

$$H_{T,50} = \sum_{i=1}^{K} (\chi/Q) \cdot Q_i \cdot IR \cdot IDF_i \cdot Icf \qquad (C\text{-}1)$$

where

$H_{T,50}$ = The 50-year dose commitment to the total body from the exposure, mrem

χ/Q = The dispersion factor for airborne contaminants for a given site, s/m^3

Q_i = The annual release quantity for radionuclide i, Ci/yr

IR = Inhalation rate constant, 20 m^3 of air/day

IDF_i = Inhalation dose factor for radionuclide i, mrem/μCi

Icf = Unit conversion factor, 11.57 day μCi/s · Ci

Submersion:

$$H_{T,50} = \sum_{i=1}^{K} (\chi/Q) \cdot Q_i \cdot SDF_i \cdot Scf \qquad (C\text{-}2)$$

where

SDF_i = Submersion dose factor for radionuclide i, mrem/yr per $\mu Ci/cm^3$

Scf = Unit conversion factor, 3.17×10^{-8} $(\mu Ci \cdot yr \cdot cm^3)/(m^3 \cdot Ci \cdot s)$

In the case of the maximum exposed individual, the maximum χ/Q is used in the calculation. This value represents the greatest concentration of the radionuclide in the air and, therefore, the greatest inhalation intake or submersion exposure. The release quantities are supplied as input. The inhalation and submersion dose factors are found in Tables C-1 and C-2.

The application of the dose factors given in the tables result in a 50-year dose commitment from a given exposure. Since the regulatory standards are for an annual dose, the dose yielded in the code would need to be altered to be compared to those standards. Instead of making that calculation, the 50-year dose commitment from an annual release is stated as an annual dose. This position results in an annual dose that overestimates the actual value, and is therefore conservative. For the radionuclides of significance in the repository dose assessment, the overestimation ranges from a factor of 2 to 10. [35]

The 50-year dose commitment from a release over the lifetime of the facility is also calculated by ISDOSE. This value is obtained by calculating the annual dose and multiplying this value by the facility life, in years.

Table C-1. Submersion Dose Conversion Factors

Radionuclides	Dose Factors* mrem/yr per $\mu Ci/cm^3$	Radionuclides	Dose Factors* mrem/yr per $\mu Ci/cm^3$
H-3	0.0	Rn-220	2.67×10^6
C-14	2.18×10^5	Rn-222	1.98×10^5
Mn-54	4.44×10^9	Pu-238	4.7×10^5
Co-60	1.31×10^{10}	Pu-239	4.26×10^5
Ni-63	0.0	Pu-240	4.63×10^5
Kr-85	2.66×10^7	Pu-241	0.0
Sr-90	1.07×10^7	Am-241	9.66×10^7
Y-90	7.33×10^7	Cm-242	5.25×10^5
Nb-95	4.03×10^9	Cm-244	4.48×10^5
Ru-106	0.0	Po-210	0.0
Te-125	5.03×10^7	Bi-212	8.25×10^9
I-129	4.29×10^7	Bi-214	4.4×10^5
Cs-134	8.14×10^9	Tu-208	4.48×10^4
Cs-137	8.36×10^6	Po-218	7.66×10^4
Ce-144	9.44×10^7	Po-214	1.01×10^9
Eu-154	6.59×10^9	Po-216	0.0
Bi-210	2.64×10^7	Po-212	2.01×10^{10}
Pb-210	6.85×10^6	Pb-212	7.55×10^8
Pb-214	1.28×10^9		

*Dose factors converted from Sievert per year per Becquerel per cubic centimeter (Sv/yr per Bq/cm^3).

Source: Kocher, D. C., 1983[22].

Table C-2. Inhalation Dose Conversion Factors

Radionuclides	Dose Factors+ mrem/μCi	Radionuclides	Dose Factors+ mrem/μCi
H-3	6.3×10^{-2}	Rn-220	N/A*
C-14	2.4×10^{-2}	Rn-222	N/A*
Mn-54	6.3	Pu-238	4.5×10^{5}
Co-60	1.5×10^{2}	Pu-239	5.2×10^{5}
Ni-63	3.1	Pu-240	5.2×10^{5}
Kr-85	N/A*	Pu-241	1.0×10^{4}
Sr-90	1.3×10^{3}	Am-241	5.2×10^{5}
Y-90	8.1	Cm-242	1.7×10^{4}
Nb-95	4.4	Cm-244	2.7×10^{5}
Ru-106	4.4×10^{2}	Po-210	7.88×10^{3}
Te-125	6.7	Bi-212	1.74×10^{1}
I-129	1.7×10^{2}	Bi-214	5.92
Cs-134	3.2×10^{1}	Tu-208	9.1×10^{3}
Cs-137	3.2×10^{1}	Po-218	1.91×10^{1}
Ce-144	3.5×10^{2}	Po-214	0.0
Eu-154	2.6×10^{2}	Po-216	0.0
Bi-210	1.9×10^{2}	Po-212	0.0
Pb-210	1.3×10^{4}	Pb-212	1.6×10^{2}
Pb-214	6.7		

*Dose factor is not applicable.
+Dose factors converted from Sievert per Becquerel (Sv/Bq).

Source: ICRP 30, ICRP 1978-1982[21].

C.2.2 Population Dose Assessment

The population dose is calculated in a similar manner as discussed for the maximum exposed individual. However, for the population case, the exposure is calculated for every person living in a specified area.

For this calculation, a population make-up is supplied as input. This make-up is in the form of a circular grid. Figure C-1 shows an example of one such grid. Each segment represents an area. The value within the segment represents the number of people who live in that area. The grid in the figure is comprised of five 10-mile wide annuli. However, the grid can represent any area. The only restraint is that no more than 20 annuli are used and that each annuli is divided into 16 sectors. These sectors represent 16 wind directions, each 22.5 degree angles.

Additional parameters for the assessment include χ/Q values for each annuli in the desired population grid and wind frequency data for the 16 directions. An example of the frequencies is presented in Table C-3.

The population dose is assessed with the following equation:

$$H_{T,50,\ population} = \sum_{n=1}^{N} \sum_{j=1}^{16} H_{T,50,\ individual,\ n} \times Pop_{n,j} \times WF_j \quad (C\text{-}3)$$

where,

$H_{T,50,\ population}$ = Population 50-year dose commitment, person-mrem

$H_{T,50,\ individual,\ n}$ = The dose commitment as calculated for the individual case. The χ/Q use is for the annulus, n, the population segment is in mrem

$Pop_{n,j}$ = The population in annulus, n, sector, j, persons

WF_j = The fraction of the time the wind blows into sector, j

As in the case of the maximum exposed individual, the dose values reported as annual doses are multiplied by the facility lifetime to calculate the 50-year commitment from the releases over the life of the plant.

C.2.3 Accident Release Dose Assessment

The dose assessment for accidental releases is the same as for routine releases outlined in the earlier section. The only differences are that the releases are in curies, i.e., the total release from the event, and the results of the assessment are only given in terms of a 50-year dose commitment.

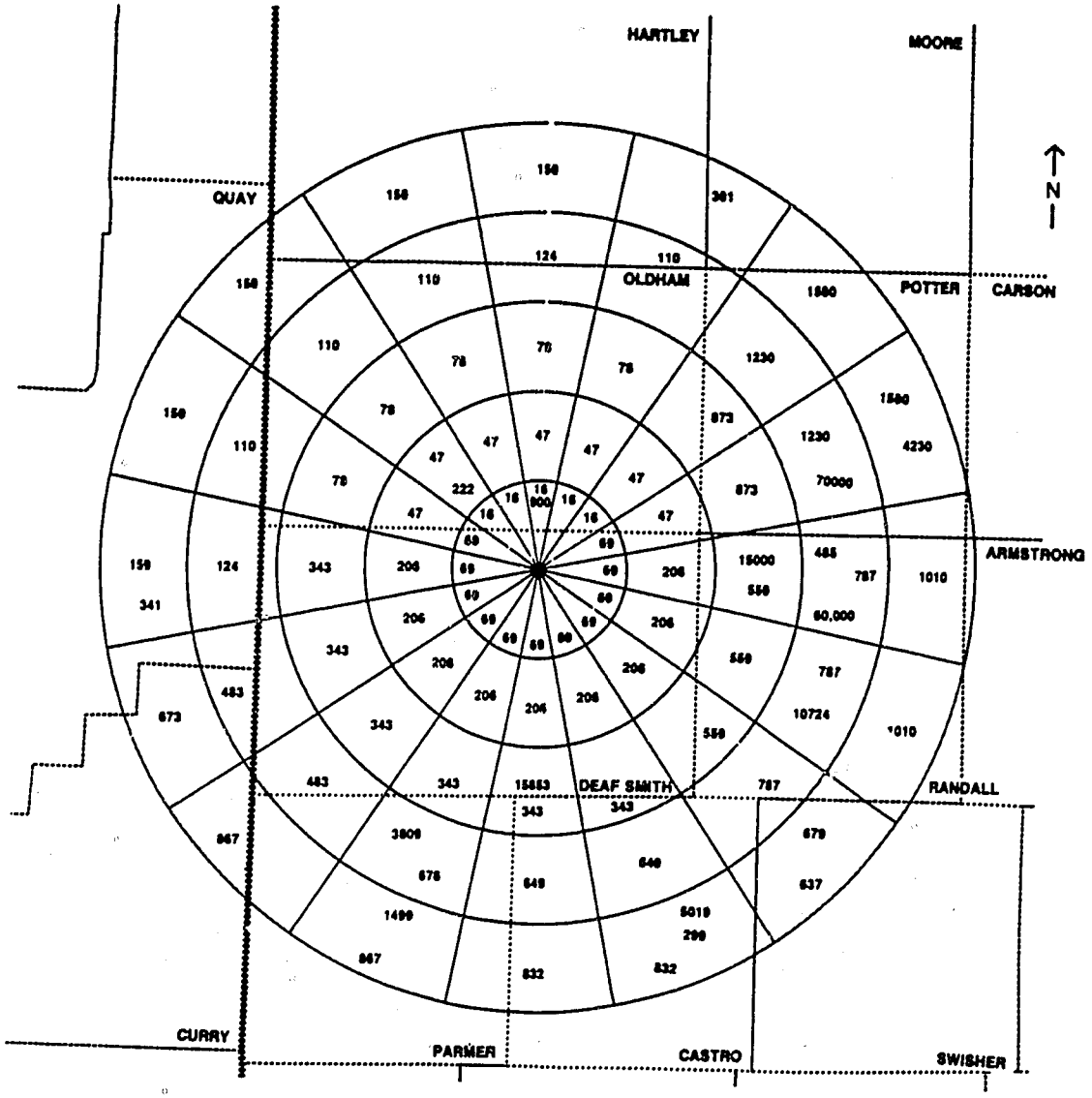


Figure C-1. Circular Grid Showing Annuli and Sections

Table C-3. Wind Frequencies Use for the First Sample Run

Direction	Wind Frequency	Wind Direction Code
N	0.19	1
NNE	0.11	2
NE	0.11	3
ENE	0.06	4
E	0.06	5
ESE	0.03	6
SE	0.04	7
SSE	0.04	8
S	0.08	9
SSW	0.05	10
SW	0.04	11
WSW	0.02	12
W	0.03	13
WNW	0.02	14
NW	0.05	15
NNW	0.07	16

C.3 RADIONUCLIDE DOSE LIBRARIES

There are three radionuclide dose factor libraries contained within ISDOSE. The first, IDF, is the inhalation dose factor library. The second, SDF, is the submersion dose factor library. The third library, RNLIB, contains the names of the 37 radionuclides that are in the two dose factors libraries. The dose factors for both inhalation and submersion are stored in the same order as the nuclides are in RNLIB. That is, the dose factor value of H-3, the first nuclide in RNLIB, is the first dose factor in IDF and SDF. The radionuclides and their submersion dose factor values are listed in Table C-1. The radionuclides and their inhalation dose factor values are listed in Table C-2.

C.4 RUNNING THE ISDOSE CODE

ISDOSE was developed to calculate submersion and inhalation doses from atmospheric releases of radionuclides from a nuclear waste repository. ISDOSE can calculate doses from both normal and accidental releases for the maximum individual and population cases.

The ISDOSE code is set up to run as a simple code. It has only one input file and one output file. The input file is set up to be read in a free format form, except for the title and radionuclide data which are set up to be read in as character data. ISDOSE reads in input data sets, runs, and then prints the output until it finds the end of the input file. There can be more than one input data set in a single ISDOSE run. The input is assigned to logical unit 8, while the output is assigned to logical unit 9. The number of

inputs varies with the type of run that is desired, maximum exposed individual, or population. The inputs that are needed for these different runs are similar. The input options are described in the input section that follows.

C.4.1 ISDOSE Input

The input consists of the title of the run, the number of annuli, the number of radionuclides, the length of time of the release, the atmospheric dispersion characteristics of the site (χ/Qs), the radionuclides that are released, and their release quantities. The input also includes the maximum individual and accident case flags. If both flags are set greater than zero, then ISDOSE reads the population and wind frequency information. If the accident case flag is set greater than zero and the maximum exposed individual flag is not, then ISDOSE reads a wind direction and the population in that direction, instead of a wind frequency and the total population.

The inputs and their descriptions are listed in the order that they are read in. All the input is in a free format, except for the radionuclide identification information which is a character string with a 10A5 format and the title which is a character string with a A65 format.

1. Title - the title. It is printed out on the top of each output page. Title is a character variable of length 65.

2. N - the number of annuli in the run. N is an integer variable that is less than or equal to 20. N is set to one on a maximum individual run.

3. K - the number of radionuclides in the run. K is an integer variable that is less than or equal to 37, the total number of radionuclides in the dose factors libraries.

4. T - the total release time. T is a real variable. T is set to one in accident case run.

5. Iflag - the maximum individual flag. The Iflag is set greater than or equal to one for a maximum individual run; it is set to less than one for a population run. Iflag is an integer variable.

6. Iflag2 - the accident case flag. The Iflag2 is set greater than or equal to one for an accident run; it is set to less than one for a nonaccident run. Iflag2 is an integer variable.

7. Chiq(N) - the χ/Qs. There is one χ/Q inputted per annuli. Chiq is a real variable with a maximum array size of 20. The maximum χ/Q is inputted in a maximum exposed individual run.

8. Rn(K) - the radionuclides. There are k radionuclide inputs. Rn is a character variable of length 5 with a maximum array size of 37. Rn is entered with a 10A5 Fortran format. The nuclides are entered in capital letters and flush right (blank spaces, if any, fill left).

9. Q(K) - the radionuclide release quantity. There is one release quantity input for each radionuclide. The units are curies per year for normal runs and total curies for the accident runs. Q is a real variable with a maximum array size of 37.

For Nonaccident Cases Runs

10. Wf(16) - the wind frequency. A wind frequency is entered for each sector. A sector is one sixteenth of an annuli, with each sixteenth representing one of the 16 wind directions. The input of the sectors starts at North, then input each sector in a clockwise motion to North-northeast finally ending at the North-northwest sector forming a circular grid. Figure C-1 gives a view of the circular grid formed by the sectors and annuli. Table C-3 gives the table of wind frequencies for Figure C-1. The data in Table C-3 is used in the first sample run. Wf is a real variable with an array size of 16. In a maximum individual run the wind frequencies are not entered, but are set to one.

11. Pop(16,N) - the population. A population value is entered for each sector of each annuli. The populations are inputted in the same order as the Wind Frequencies. The sectors start at the North sector; then run in a clockwise motion to the North-northeast sector, finally ending at the North-northwest sector. The sectors of the center annuli inputted first followed by the sectors of the next annuli. Figure C-1 gives a view of the circular grid formed by the annuli and the sectors. The values of Figure C-1 are used in the first sample run. Pop is a real variable, a double subscripted array, with the first subscript of 16 and a second a maximum of 20. In a maximum individual run the population is not entered, but is set equal to one.

For Accident Cases Runs

10. Iwd - the wind direciton. It is entered in an accident case. Iwd is an integer that represents the wind direction in an accident case. The values run from one to 16 with one being north running clockwise to 16 representing north-northwest. The values that represent the wind directions are listed in Table C-3. Iwd is not entered in a maximum individual run.

11. Pop(Iwd,N) - the population. In an accident case the population is entered for each annuli and for each sector in the wind direction set by Iwd. Pop is a real variable, a double subscripted array, with the first subscript value set to equal Iwd and the second to a limit of 20. In a maximum individual run the population is not entered, but is set equal to one.

C.4.2 ISDOSE Output

The ISDOSE output is in a preset format. The date and title are printed first to identify the run. Next, the input variables are echoed out. This is done so input data can be found quickly and easily and debugging can be done.

After the input is written, ISDOSE prints the dose commitment and the total dose for each of the nuclides entered. For accident runs, ISDOSE prints the 50-year dose commitment. For nonaccident runs, ISDOSE prints both the annual dose from a 1-year release and 50-year dose commitment from the total release. For both the 1-year and the 50-year release ISDOSE prints the percentage of the total dose contributed by each of the nuclides. The data set run number is also printed to identify the run.

C.4.3 Warning and Error Messages

ISDOSE has one warning message and one error message. The warning message is for the inhalation dose factor library. The warning message states "***Warning -- KR85 is not in Inhalation Library." This is printed because for three nuclides in the radionuclide library (KR85, RN220, and RN222) the inhalation dose factors are not applicable, while submersion dose factors are. ISDOSE sets their inhalation dose factors to zero.

The error message prints out when a nuclide is not found in the library or is not in the correct format. To be read properly by ISDOSE the nuclide must be entered in capital letters, flush right in a 5 character format (blank spaces fill left). For example, I-129 would be entered as ' I129', while Rn-222 would be entered as 'RN222'. If this error is flagged, the error message is printed out; and the data set that flagged the error is skipped. ISDOSE would then go on to the next data set.

C.5 SAMPLE RUNS

This section presents several sample runs. The first sample run uses the population input information in Figure C-1 and the wind frequency information in Table C-3. The second sample run uses the same information as the first, but flags the accidental release run. The third sample run also uses the same input data as the previous two, but it is set up as a maximum individual run, so the population and wind frequency data are not entered. The fourth sample run is a maximum individual accident case run. The fifth sample run flags all of the error and warning messages that are in the code.

C.5.1 Sample Input File

```
Sample Run Number One - Population Run
 5  16  26  0  0
8.93e-7 2.01e-7 9.62e-8 6.16e-8 4.49e-8
   H3  C14 KR85 I129PO218PB214BI214PO214PB210BI210
PO210PO216PB212BI212PO212TU208
3.2E1,2.6E-1,1.9E4,3.2E-2,2.9E-4,2.9E-4,2.9E-4,2.9E-4,2.9E-4,
2.9E-4,2.9E-4,2.2E-4,2.2E-4,2.2E-4,1.4E-4,7.8E-5
.19 .11 .11 .06 .05 .03 .04 .04 .08 .05 .04 .02 .03 .02 .05 .07
916. 16. 16. 69. 69. 69. 69. 69. 69. 69. 69. 69. 69. 16. 16.
47. 47. 47. 47. 206. 206. 206. 206. 206. 206. 206. 206. 206. 47. 269. 47.
78. 78. 873. 873. 15600. 559. 559. 343. 16200 343. 343. 343. 343. 78. 78. 78.
124. 110. 1230. 71200. 61300. 11200. 787. 649. 849. 4490. 483. 483. 124. 110.
110. 110.
159. 301. 1580. 5810. 1010. 1010. 1320. 6150. 832. 2370. 867. 673. 500. 159.
159. 159.
Sample Run Number Two - Accident Population Run
 5  16  1  0  1
8.93e-7 2.01e-7 9.62e-8 6.16e-8 4.49e-8
   H3  C14 KR85 I129PO218PB214BI214PO214PB210BI210
PO210PO216PB212BI212PO212TU208
3.2E1,2.6E-1,1.9E4,3.2E-2,2.9E-4,2.9E-4,2.9E-4,2.9E-4,2.9E-4,
2.9E-4,2.9E-4,2.2E-4,2.2E-4,2.2E-4,1.4E-4,7.8E-5
 4  69. 47. 873. 71200. 5810.
Sample Run Number Three - Maximum Individual
 1  16  26  1  0
8.93e-7
   H3  C14 KR85 I129PO218PB214BI214PO214PB210BI210
PO210PO216PB212BI212PO212TU208
3.2E1,2.6E-1,1.9E4,3.2E-2,2.9E-4,2.9E-4,2.9E-4,2.9E-4,2.9E-4,
2.9E-4,2.9E-4,2.2E-4,2.2E-4,2.2E-4,1.4E-4,7.8E-5
Sample Run Number Four - Maximum Individual Accident Run
 1  16  1  1  1
8.93e-7
   H3  C14 KR85 I129PO218PB214BI214PO214PB210BI210
PO210PO216PB212BI212PO212TU208
3.2E1,2.6E-1,1.9E4,3.2E-2,2.9E-4,2.9E-4,2.9E-4,2.9E-4,2.9E-4,
2.9E-4,2.9E-4,2.2E-4,2.2E-4,2.2E-4,1.4E-4,7.8E-5
Sample Run Number Five - Error and Warning Messages
 1  4 1 1 1
8.93e-7
 KR85RN220RN222AG107
1.0 1.0 1.0 1.0
```

C.5.2 Sample Output File

```
**************Isdose V1.0*****************      Date 31-JUL-85

Sample Run Number One - Population Run

    The Amount of Time is      26.0 years.

    The X/Q s Used(sec/cubic meters):  8.930000E-07
                                       2.010000E-07
                                       9.820000E-08
                                       6.160000E-08
                                       4.490000E-08

    The Radionuclides and Their Releases(Ci/yr):

                          H3       32.0000
                         C14      0.260000
                        KR85       19000.0
                        I129     3.200000E-02
                        PO218    2.900000E-04
                        PB214    2.900000E-04
                        BI214    2.900000E-04
                        PO214    2.900000E-04
                        PB210    2.900000E-04
                        BI210    2.900000E-04
                        PO210    2.900000E-04
                        PO216    2.200000E-04
                        PB212    2.200000E-04
                        BI212    2.200000E-04
                        PO212    1.400000E-04
                        TU208    7.800000E-05

 Wind Frequencies and Populations:

     Wind Freq
   N   0.190    916.     47.     78.     124.     159.
 NNE   0.110     16.     47.     78.     110.     301.
  NE   0.110     16.     47.    873.    1230.    1580.
 ENE   0.060     69.     47.    873.   71200.    5810.
   E   0.060     69.    206.  15600.   61300.    1010.
 ESE   0.030     69.    206.    559.   11200.    1010.
  SE   0.040     69.    206.    559.     787.    1320.
 SSE   0.040     69.    206.    343.     649.    6150.
   S   0.080     69.    206.  16200.     649.     832.
 SSW   0.050     69.    206.    343.    4490.    2370.
  SW   0.040     69.    206.    343.     483.     867.
 WSW   0.020     69.    206.    343.     483.     673.
   W   0.030     69.    206.    343.     124.     500.
 WNW   0.020     69.     47.     78.     110.     159.
  NW   0.050     16.    269.     78.     110.     159.
 NNW   0.070     16.     47.     78.     110.     159.

***Warning -- KR85 not in Inhalation Dose Factor Library, assumed to be zero
```

Sample Run Number One - Population Run Date 31-JUL-85

Annual dose from a 1 year release

Radionuclide	Inhalation Dose(person-mrem)		Submersion Dose(person-mrem)	
H3	4.25897E-02	14.80%	0.00000E+00	0.00%
C14	1.31763E-04	0.05%	1.89701E-06	0.00%
KR85	0.00000E+00	0.00%	16.915	100.00%
I129	0.11487	39.94%	4.59459E-05	0.00%
PO218	1.16961E-04	0.04%	7.43474E-10	0.00%
PB214	4.10282E-05	0.01%	1.24236E-05	0.00%
BI214	3.62518E-05	0.01%	4.27061E-09	0.00%
PO214	0.00000E+00	0.00%	9.80299E-06	0.00%
PB210	7.96070E-02	27.68%	6.64856E-08	0.00%
BI210	1.16348E-03	0.40%	2.56237E-07	0.00%
PO210	4.82541E-02	16.78%	0.00000E+00	0.00%
PO216	0.00000E+00	0.00%	0.00000E+00	0.00%
PB212	7.43280E-04	0.26%	5.55916E-06	0.00%
BI212	8.08317E-05	0.03%	6.07457E-05	0.00%
PO212	0.00000E+00	0.00%	9.41810E-05	0.00%
TU208	1.49881E-08	0.00%	1.16953E-10	0.00%
Total	0.28762	100.00%	16.915	100.00%

50 Year dose commitment from a 26.000 year release

Radionuclide	Inhalation Dose(person-mrem)		Submersion Dose(person-mrem)	
H3	1.1068	14.80%	0.00000E+00	0.00%
C14	3.42585E-03	0.05%	4.93222E-05	0.00%
KR85	0.00000E+00	0.00%	439.79	100.00%
I129	2.9866	39.94%	1.19459E-03	0.00%
PO218	3.04099E-03	0.04%	1.93303E-08	0.00%
PB214	1.06673E-03	0.01%	3.23013E-04	0.00%
BI214	9.42547E-04	0.01%	1.11036E-07	0.00%
PO214	0.00000E+00	0.00%	2.54878E-04	0.00%
PB210	2.0698	27.68%	1.72863E-06	0.00%
BI210	3.02507E-02	0.40%	6.66215E-06	0.00%
PO210	1.2546	16.78%	0.00000E+00	0.00%
PO216	0.00000E+00	0.00%	0.00000E+00	0.00%
PB212	1.93253E-02	0.26%	1.44538E-04	0.00%
BI212	2.10162E-03	0.03%	1.57939E-03	0.00%
PO212	0.00000E+00	0.00%	2.44871E-03	0.00%
TU208	3.89690E-07	0.00%	3.04078E-09	0.00%
Total	7.4780	100.00%	439.80	100.00%

***End of Run Number 1

**********Isdose V1.0********** Date 31-JUL-85

Sample Run Number Two - Accident Population Run

Accident Case Run

The X/Q s Used(sec/cubic meters): 8.930000E-07
2.010000E-07
9.620000E-08
6.160000E-08
4.490000E-08

The Radionuclides and Their Releases(Ci):

H3	32.0000
C14	0.260000
KR85	19000.0
I129	3.200000E-02
PO218	2.900000E-04
PB214	2.900000E-04
BI214	2.900000E-04
PO214	2.900000E-04
PB210	2.900000E-04
BI210	2.900000E-04
PO210	2.900000E-04
PO216	2.200000E-04
PB212	2.200000E-04
BI212	2.200000E-04
PO212	1.400000E-04
TU208	7.800000E-05

Wind Frequencies and Populations:

	Wind Freq					
N	0.000	0.	0.	0.	0.	0.
NNE	0.000	0.	0.	0.	0.	0.
NE	0.000	0.	0.	0.	0.	0.
ENE	1.000	69.	47.	873.	71200.	5810.
E	0.000	0.	0.	0.	0.	0.
ESE	0.000	0.	0.	0.	0.	0.
SE	0.000	0.	0.	0.	0.	0.
SSE	0.000	0.	0.	0.	0.	0.
S	0.000	0.	0.	0.	0.	0.
SSW	0.000	0.	0.	0.	0.	0.
SW	0.000	0.	0.	0.	0.	0.
WSW	0.000	0.	0.	0.	0.	0.
W	0.000	0.	0.	0.	0.	0.
WNW	0.000	0.	0.	0.	0.	0.
NW	0.000	0.	0.	0.	0.	0.
NNW	0.000	0.	0.	0.	0.	0.

***Warning -- KR85 not in Inhalation Dose Factor Library, assumed to be zero

Sample Run Number Two - Accident Population Run Date 31-JUL-85

50 year dose commitment

Radionuclide	Inhalation Dose(person-mrem)		Submersion Dose(person-mrem)	
H3	0.19361	14.80%	0.00000E+00	0.00%
C14	5.99269E-04	0.05%	8.62773E-06	0.00%
KR85	0.00000E+00	0.00%	76.931	100.00%
I129	0.52244	39.94%	2.08965E-04	0.00%
PO218	5.31947E-04	0.04%	3.38137E-09	0.00%
PB214	1.86599E-04	0.01%	5.65034E-05	0.00%
BI214	1.64876E-04	0.01%	1.94230E-08	0.00%
PO214	0.00000E+00	0.00%	4.45847E-05	0.00%
PB210	0.36206	27.68%	3.02381E-07	0.00%
BI210	5.29162E-03	0.40%	1.18538E-06	0.00%
PO210	0.21946	16.78%	0.00000E+00	0.00%
PO216	0.00000E+00	0.00%	0.00000E+00	0.00%
PB212	3.38049E-03	0.26%	2.52834E-05	0.00%
BI212	3.67629E-04	0.03%	2.76276E-04	0.00%
PO212	0.00000E+00	0.00%	4.28342E-04	0.00%
TU208	6.81669E-08	0.00%	5.31911E-10	0.00%
Total	1.3081	100.00%	76.932	100.00%

***End of Run Number 2

2 OF 2

```
**************Isdose V1.0*****************     Date 31-JUL-85

Sample Run Number Three - Maximum Individual

    The Amount of Time is     26.0 years.

    The X/Q s Used(sec/cubic meters):  8.930000E-07

    The Radionuclides and Their Releases(Ci/yr):

                      H3       32.0000
                     C14      0.260000
                    KR85       19000.0
                    I129     3.200000E-02
                   PO218     2.900000E-04
                   PB214     2.900000E-04
                   BI214     2.900000E-04
                   PO214     2.900000E-04
                   PB210     2.900000E-04
                   BI210     2.900000E-04
                   PO210     2.900000E-04
                   PO216     2.200000E-04
                   PB212     2.200000E-04
                   BI212     2.200000E-04
                   PO212     1.400000E-04
                   TU208     7.800000E-05

 This is a Maximum Individual Dose Run


***Warning -- KR85 not in Inhalation Dose Factor Library, assumed to be zero
```

Sample Run Number Three - Maximum Individual

Date 31-JUL-85

Annual dose from a 1 year release

Radionuclide	Inhalation Dose(mrem)		Submersion Dose(mrem)	
H3	2.52040E-03	14.80%	0.00000E+00	0.00%
C14	7.80125E-06	0.05%	1.12315E-07	0.00%
KR85	0.00000E+00	0.00%	1.0015	100.00%
I129	6.801C9E-03	39.94%	2.72030E-06	0.00%
P0218	6.92486E-06	0.04%	4.40185E-11	0.00%
PB214	2.42914E-06	0.01%	7.35558E-07	0.00%
BI214	2.14634E-06	0.01%	2.52848E-10	0.00%
P0214	0.00000E+00	0.00%	5.80401E-07	0.00%
PB210	4.71325E-03	27.68%	3.93638E-09	0.00%
BI210	6.88860E-05	0.40%	1.51709E-08	0.00%
P0210	2.85696E-03	16.78%	0.00000E+00	0.00%
P0216	0.00000E+00	0.00%	0.00000E+00	0.00%
PB212	4.40070E-05	0.26%	3.29138E-07	0.00%
BI212	4.78577E-06	0.03%	3.59654E-06	0.00%
P0212	0.00000E+00	0.00%	5.57613E-06	0.00%
TU208	8.87392E-10	0.00%	6.92439E-12	0.00%
	---	---	---	---
Total	1.70287E-02	100.00%	1.0015	100.00%

50 Year dose commitment from a 26.000 year release

Radionuclide	Inhalation Dose(mrem)		Submersion Dose(mrem)	
H3	6.55305E-02	14.80%	0.00000E+00	0.00%
C14	2.02832E-04	0.05%	2.92020E-06	0.00%
KR85	0.00000E+00	0.00%	26.039	100.00%
I129	0.17683	39.94%	7.07277E-05	0.00%
P0218	1.80048E-04	0.04%	1.14448E-09	0.00%
PB214	8.31578E-05	0.01%	1.91245E-05	0.00%
BI214	5.58049E-05	0.01%	6.57405E-09	0.00%
P0214	0.00000E+00	0.00%	1.50904E-05	0.00%
PB210	0.12254	27.68%	1.02346E-07	0.00%
BI210	1.79104E-03	0.40%	3.94443E-07	0.00%
P0210	7.42809E-02	16.78%	0.00000E+00	0.00%
P0216	0.00000E+00	0.00%	0.00000E+00	0.00%
PB212	1.14418E-03	0.26%	8.55759E-06	0.00%
BI212	1.24430E-04	0.03%	9.35101E-05	0.00%
P0212	0.00000E+00	0.00%	1.44979E-04	0.00%
TU208	2.30722E-08	0.00%	1.80034E-10	0.00%
	---	---	---	---
Total	0.44275	100.00%	26.039	100.00%

***End of Run Number 3

```
**************Isdose V1.0*****************      Date 31-JUL-85

Sample Run Number Four - Maximum Individual Accident Run

    Accident Case Run

    The X/Q s Used(sec/cubic meters):  8.930000E-07

    The Radionuclides and Their Releases(Ci):

                      H3        32.0000
                     C14       0.280000
                    KR85        19000.0
                    I129       3.200000E-02
                   PO218       2.900000E-04
                   PB214       2.900000E-04
                   BI214       2.900000E-04
                   PO214       2.900000E-04
                   PB210       2.900000E-04
                   BI210       2.900000E-04
                   PO210       2.900000E-04
                   PO216       2.200000E-04
                   PB212       2.200000E-04
                   BI212       2.200000E-04
                   PO212       1.400000E-04
                   TU208       7.800000E-05


   This is a Maximum Individual Dose Run


  ***Warning -- KR85 not in Inhalation Dose Factor Library, assumed to be zero
```

Sample Run Number Four - Maximum Individual Accident Run Date 31-JUL-85

50 year dose commitment

Radionuclide	Inhalation Dose(mrem)		Submersion Dose(mrem)	
H3	2.52040E-03	14.80%	0.00000E+00	0.00%
C14	7.80125E-06	0.05%	1.12315E-07	0.00%
KR85	0.00000E+00	0.00%	1.0015	100.00%
I129	6.80109E-03	39.94%	2.72030E-06	0.00%
PO218	6.92486E-06	0.04%	4.40185E-11	0.00%
PB214	2.42914E-06	0.01%	7.35558E-07	0.00%
BI214	2.14634E-06	0.01%	2.52848E-10	0.00%
PO214	0.00000E+00	0.00%	5.80401E-07	0.00%
PB210	4.71325E-03	27.68%	3.93638E-09	0.00%
BI210	6.88860E-05	0.40%	1.51709E-08	0.00%
PO210	2.85696E-03	16.78%	0.00000E+00	0.00%
PO216	0.00000E+00	0.00%	0.00000E+00	0.00%
PB21[illegible]	4.40070E-05	0.26%	3.29138E-07	0.00%
BI212	4.78577E-06	0.03%	3.59654E-06	0.00%
PO212	0.00000E+00	0.00%	5.57613E-06	0.00%
TU208	8.87392E-10	0.00%	6.92439E-12	0.00%
Total	1.70287E-02	100.00%	1.0015	100.00%

***End of Run Number 4

```
**************Isdose V1.0*****************      Date 31-JUL-85

Sample Run Number Five - Error and Warning Messages

    Accident Case Run

    T   X/Q s Used(sec/cubic meters):  8.930000E-07

    The Radionuclides and Their Releases(Ci):

                    KR85        1.00000
                    RN220       1.00000
                    RN222       1.00000
                    AG107       1.00000

    This is a Maximum Individual Dose Run


***Warning -- KR85 not in Inhalation Dose Factor Library, assumed to be zero

***Warning --RN220 not in Inhalation Dose Factor Library, assumed to be zero

***Warning --RN222 not in Inhalation Dose Factor Library, assumed to be zero

***Error --AG107  is not in Nuclide Library, input data set skipped


***End of Run Number  5
```

C.6 PROGRAM LISTING

```
      Program ISDOSE
C-----------------------------------------------------------------------
C
C
C     Version 1.0
C
C     Author   J. Furr
C
C     Language   Fortran
C
C     Description
C
C           This program can calculate Inhalation and Submersion
C           doses.  It contains two libraries, one for inhalation abd
C           one for submersion, each with the same 37 radionuclides and
C           their dose factors.  It can calculate the doses for normal
C           and accidental releases.  It can also calculate either
C           population or maximum individual doses.
C
C     Radionuclides contained in Libraries
C
C      H3       C14      MN54     CO60     NI63     KR85     SR90
C      Y90      NB95     RU106    TE125    I129     CS134    CS137
C     CE144    EU154    TU208    BI210    PO210    PB210    BI212
C     PB212    PO214    BI214    PB214    PO214    PO216    PO218
C     RN220    RN222    PU238    PU239    PU240    PU241    AM241
C     CM242    CM244    PO210
C
C
C     Variables used
C
C          Chiq(20)  - The Chi/q value used for each sector
C          Day       - The date
C          Dsf       - Dose factor variable
C          Icf       - Unit conversion factor
C          Idf(37)   - Inhalation dose factor library
C          Idose(37) - Inhalation dose for each inputted Radionuclide
C          Idsum     - Summation of the Inhalation dose
C          Iflag     - Maximum Individual dose flag
C          Iflag2    - Accident case flag
C          Index     - Radionuclide library search flag
C          Indose    - Inhalation dose for each nuclide for each sector
C          Ipert     - Radionuclide Inhalation dose percentages
C          Ir        - Inhalation rate
C          Ispert    - Inhalation percentages summation
C          Iwd       - Wind Direction Code entered in an Accident Run
C          K         - The number of Radionuclides
C          N         - The number of annuli
C          Pop(16,20)- Population for each sector
C          Q(37)     - Radionuclide release quanity
C          Rn(37)    - Radionuclides used
C          Rnlib(37) - The radionuclides library
C          Scf       - Units convertion factor
C          Sdf(37)   - Submersion dose factor library
C          Sdose(37) - Submersion dose for each inputted Radionuclide
C          Sdsum     - Summation of the Submersion dose
C          Sbdose    - Submersion dose for each nuclide for each sector
```

```
C             Spert     -  Radionuclide Submersion dose percentages
C             Sspert    -  Submersion percentages summation
C             T         -  Time
C             Title     -  The title of the run
C             Wf(16)    -  Wind frequencies for each sector
C
C
C-------------------------------------------------------------------------

      Dimension Chiq(20),WF(16),Pop(16,20),Q(37),Sdf(37)
      Character*5 Rn(37),Rnlib(37)
      Character Day*9,Title*65
      Character*3 Wind(16)
      Real Icf,Ir,Scf,Idose(37),Indo:   t,Sdose(37),Sbdose,Idf(37)
     +     ,Ipert,Idsum,Ispert

      Data Rnlib /'   H3',' C14',' MN54',' C060',' NI63',' KR85',
     +    ' SR90',' Y90',' NB95','RU106','TE125',' I129','CS134',
     +    'CS137','CE144','EU154','BI210','PB210','PB212','PB214',
     +    'RN220','RN222','PU238','PU239','PU240','PU241','AM241',
     +    'CM242','CM244','PO210','BI212','BI214','TU208','PO218',
     +    'PO214','PO216','PO212'/

      Data Idf  /6.3E-2,2.4E-2,6.3,1.5E2,3.1,-99.99,1.3E3,8.1,4.4,4.4E2,
     +           6.7,1.7E2,4.8E1,3.2E1,3.5E2,2.6E2,1.9E2,1.3E4,1.6E2,
     +           6.7,-99.99,-99.99,4.4E5,5.2E5,5.2E5,1.0E4,5.2E5,
     +           1.7E4,2.7E5,7.88E3,1.74E1,5.92,9.10E-3,1.91E1,0.0,
     +           0.0,0.0/

      Data Sdf  /0.0,2.18E5,4.44E9,1.31E10,0.0,2.66E7,1.07E7,7.33E7,
     +           4.03E9,0.0,5.03E7,4.29E7,8.14E9,8.36E6,9.44E7,6.59E9,
     +           2.64E7,8.85E6,7.55E8,1.28E9,2.67E6,1.98E6,4.7E5,4.26E5,
     +           4.63E5,0.0,9.66E7,5.25E5,4.48E5,0.0,8.25E9,4.4E5,
     +           4.48E4,7.66E4,1.01E9,0.0,2.01E10/

      Data Wind /'  N','NNE',' NE','ENE','  E','ESE',' SE','SSE','  S',
     +           'SSW',' SW','WSW','  W','WNW',' NW','NNW'/

      Scf=3.17E-08      ! (Micro-Ci ) x m**3 x yr/Ci x CM**3 x Sec
      Icf=11.57         ! Day x (Micro-Ci) / sec x Ci
      Ir=20.            ! M**3 x (air breathed) / day

      Do In=1,10000
C
C     K is number of Radionuclides,N is number of annuli:
C
      Read(8,21,end=999)Title
21    Format(a65)
      Read(8,*)N,K,T,Iflag,Iflag2
      If(iflag .gt. 0)N=1
      Read(8,*)(Chiq(I),I=1,N)
      Read(8,1)(Rn(I),I=1,K)
      Read(8,*)(Q(I),I=1,K)
C
C     Iflag check for Maximum Individual Dose Run
C
      If(iflag.gt.0)then
         Pop(1,1)=1
         Wf(1)=1
      End if
```

```
C
C     Iflag2 check for Accident Case Run
C
      If(Iflag2.gt.0)then
          t=1.0
          If(Iflag .le. 0)then
             Do i=1,16
                Wf(i)=0.0
                Do j=1,20
                   Pop(i,j)=0.0
                End do
             End do

C       If not Maximum Individual run input the  Wind direction and population

             Read(8,*)Iwd,(Pop(Iwd,I),I=1,N)
             Wf(Iwd)=1.0

          end if
       end if

C
C     Normal Case Population and Wind frequency Read
C
      If(iflag.le.0.and.iflag2.le.0)then
         Read(8,*)(Wf(I),I=1,16)
         Read(8,*)((Pop(I,J),I=1,16),J=1,N)
      End if

    1 Format(10a5)
C
C     Echo out the Input Variables
C

      Call Date(Day)

      Write(9,99)Day
 99   Format('1','**************Isdose V1.0*****************',5X,
     $       'Date ',a9,/)
      Write(9,100)Title
 100  Format('/',a65/)


      If(iflag2.gt.0)then
         Write(9,1003)
 1003    Format('    Accident Case Run ')
         Write(9,101)Chiq(1)
 101     Format('    The X/Q s Used(sec/cubic meters): ',1pG13.6,)
         Do i=2,N
           Write(9,102)Chiq(i)
 102       Format('                                      ',1pG13.6,)
          End do
            Write(9,103)
 103        Format(/,'    The Radionuclides and Their Releases',
     $              '(Ci): ',/)

       else
            Write(9,1005)T
 1005       format('  The Amount of Time is ',f8.1,' years.')
            Write(9,101)Chiq(1)
```

```
          Do i=2,N
            Write(9,103)Chiq(i)
          End do
          Write(9,1035)
1035      Format(/,'    The Radionuclides and Their Releases',
     $               '(Ci/yr): ',/)
      End if
      Do i=1,K
         Write(9,104)Rn(i),Q(i)
104      Format('                    ',a5,5x,1pG13.6)
      End do

      If(Iflag.le.0)then
         Write(9,105)
105      Format(/' Wind Frequencies and Populations:'/)
         Write(9,106)
106      format(4x,' Wind Freq',)
         Do i=1,16
            Write(9,107)Wind(i),Wf(i),(Pop(I,J),J=1,N)
107         Format(' ',a3,F8.3,1x,12(F7.0,1x))
         End do
      Else
         Write(9,108)
108      Format(//'  This is a Maximum Individual Dose Run'//)
      End if

      Idsum=0.
      Sdsum=0.

C
C    Calculation of Inhalation Dose
C
C    Find inhalation Dose Factors from the Library
C
      Do J=1,K

         Idose(j)=0.
         Sdose(j)=0.
         Index=-5


         Do I=1,37
            If(Rnlib(I).eq.Rn(J))Index=I
         End do
C
C    Test to see if Element is in library
C
          If(Index.lt.0)then
              Write(9,10)Rn(J)
  10          Format(/' ***Error --',A5,'  is not in Nuclide Library',
     $                ', input data set skipped')
              Go to 998
          end if

          Dsf=Idf(Index)*Ir

          If(Dsf.lt.0)Then
            Write(9,20)Rn(J)
  20        Format(/' ***Warning --',A5,' not in Inhalation Dose ',
     $             'Factor Library, assumed to be zero')
```

```
            Dsf=0.0
          End if

          Do I=1,N
             Do Ik=1,16
               Indose=Q(J)*Chiq(I)*Pop(Ik,I)*Wf(Ik)*Dsf
               Idose(j)=Indose+Idose(j)
             End Do
          End Do


C
C      Find the Submersion Dose Factor
C


          Dsf=Sdf(Index)*Scf
          Do I=1,N
             Do Ik=1,16
                Sbdose=Q(J)*Chiq(I)*Pop(Ik,I)*Wf(Ik)*Dsf
                Sdose(j) = Sdose(j) +Sbdose
             End Do
          End Do

          Idsum=Idsum + Idose(j)
          Sdsum=Sdsum + Sdose(j)

       End do
C
C      Print the Output
C

          Write(9,13)Title,Day
   13     Format('1',a65,' Date ',a9,/)

       If(iflag2.le.0)then

          Write(9,49)
   49     Format(' Annual dose from a 1 year release',/)

          If(Iflag .le. 0)then
             Write(9,25)
          Else
             Write(9,26)
          End if

          Ispert=0.0
          Sspert=0.0
          Do j=1,K
             Ipert=(Idose(j)/Idsum)*100.
             Spert=(Sdose(j)/Sdsum)*100.
             Ispert=Ipert+Ispert
             Sspert=Spert+Sspert

             Write(9,30)Rn(J),Idose(j),Ipert,Sdose(j),Spert
   30        Format(10x,A5,2(5x,1pG13.5,5x,0pf6.2,'%'))
          End do

          Write(9,35)
   35     Format(15x,5x,13('-'),5x,6('-'),6x,13('-'),5x,6('-'))
```

```
         Write(9,40)Idsum,Ispert,Sdsum,Sspert
40       Format(10x,'Total',2(5x,1pG13.5,5x,0pF6.2,'%'))
      end if

      If(iflag2.gt.0)then
         Write(9,14)
14       Format(' ',//' 50 year dose commitment'/)
      else
         Write(9,15)T
      end if

         If(Iflag .le. 0)then
            Write(9,25)
         Else
            Write(9,26)
         End if

15       Format(' ',//' 50 Year dose commitment from a ',f8.3,
     +        ' year release'/)
25       Format(/,7x,'Radionuclide',2x,
     +      'Inhalation Dose(person-mrem)',
     +       2x,'Submersion Dose(person-mrem)'/)
26       Format(/,7x,'Radionuclide',2x,
     +      'Inhalation Dose(mrem)',
     +       9x,'Submersion Dose(mrem)'/)

      Idsum=Idsum*t
      sdsum=sdsum*t

      Ispert=0.0
      Sspert=0.0
      Do j=1,K
         Idose(J)=Idose(j)*t
         Sdose(j)=Sdose(j)*t
         Ipert=Idose(j)/Idsum*100.
         Spert=Sdose(j)/Sdsum*100.
         Ispert=Ipert+Ispert
         Sspert=Spert+Sspert

         Write(9,30)Rn(J),Idose(j),Ipert,Sdose(j),Spert
      End do

      Write(9,35)
      Write(9,40)Idsum,Ispert,Sdsum,Sspert
998   write(9,16)In
16    Format(///,' ***End of Run Number',i3)

      End do

999   Stop
      End
```

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